

AD/A-002 733

TESTING PROCEDURES FOR OPEN CIRCUIT
AIR DIVING HELMETS AND SEMI-CLOSED
CIRCUIT MIXED GAS DIVING HELMETS

S. D. Reimers

Navy Experimental Diving Unit
Washington, D. C.

18 December 1973

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM	
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER AD/A-002233	
4. TITLE (and Subtitle) Test Protocol Open Circuit and Diving Helmets and Semi-Closed Circuit Mixed Gas Diving Helmets		5. TYPE OF REPORT & PERIOD COVERED	
7. AUTHOR(s) S. D. Reimers		6. PERFORMING ORG. REPORT NUMBER	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Navy Experimental Diving Unit Washington Navy Yard Washington, D. C. 20374		8. CONTRACT OR GRANT NUMBER(s)	
11. CONTROLLING OFFICE NAME AND ADDRESS		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE 18 Dec 1973	
		13. NUMBER OF PAGES 114	
		15. SECURITY CLASS. (of this report) Unclassified	
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release, distribution unlimited			
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)			
18. SUPPLEMENTARY NOTES			
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)			
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)			

DD FORM 1473
1 JAN 73

EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

NAVY EXPERIMENTAL DIVING UNIT
WASHINGTON NAVY YARD
WASHINGTON, D. C. 20374

NAVXDIVINGU REPORT 20-74

TESTING PROCEDURES FOR
OPEN CIRCUIT AIR DIVING HELMETS
AND
SEMI-CLOSED CIRCUIT MIXED GAS
DIVING HELMETS

S. D. REIMERS

18 December 1973

Approved for public release; distribution unlimited.

Submitted:

S. D. Reimers
S. D. Reimers
LT., USNR

ia

Approved:

T. L. Hawkins
T. L. Hawkins
LCDR, USN
Officer in Charge
(Acting)

TABLE OF CONTENTS

	<u>Page No.</u>
TABLE OF CONTENTS	i
LIST OF FIGURES AND TABLES	iii
LIST OF SYMBOLS AND TERMS	iv
I. INTRODUCTION	1
II. DESCRIPTION OF THE EQUIPMENT TESTED	3
A. Serial Numbers	3
B. Photographs	3
C. Physical Description	3
III. PERFORMANCE TESTS	5
A. Open Circuit Air Helmets	5
1. Helmet Pressure-Volume Characteristics (Compliance)	5
2. Air Supply System and Exhaust Valve Tests . . .	12
3. Sound Level Tests, Open Circuit Air	20
4. Ventilation Tests, Open Circuit Air	31
5. Manned Dives, Subjective Evaluation	43
6. Manned Dives, Physiological Testing	50
B. Semi-Closed Circuit Mixed Gas Helmets	51
1. Helmet Pressure-Volume Characteristics (Compliance)	51
2. Venturi Efficiency and Exhaust Valve Performance Tests	54
3. Sound Level Tests, Semi-Closed Circuit Mixed Gas Helmet	61
4. Ventilation Tests, Semi-Closed Circuit Mixed Gas	71
5. CO ₂ Absorbent Canister Duration Tests	83

TABLE OF CONTENTS
(Continued)

	<u>Page No.</u>
6. Manned Dives, Subjective Evaluation, Semi-closed Circuit Mixed Gas Helmet	88
7. Manned Dives, Physiological Testing	96
8. Emergency Air Mode Tests	97
IV. INSTRUMENT SPECIFICATIONS	99
REFERENCES	100
APPENDIX A	101

LIST OF FIGURES

	<u>Page No.</u>
1. Test Equipment Set-Up, Open Circuit Air Helmet Compliance Tests	7
2. Sample Helmet Compliance Test Results	11
3. Test Equipment Set-up, Air Supply System and Exhaust Valve Tests	14
4. Sample Graph, Helmet Flow Rate Versus Depth and Air Control Valve Position	18
5. Sample Graph, Helmet Pressure Versus Helmet Flow Rate and Exhaust Valve Position at a Selected Depth	19
6. Test Set-Up, Open Circuit Air Sound Level Tests	23
7. Equivalent A-Weighted Sound Level Contours	30
8. Currently Accepted Daily Noise Exposure Limits (2) (3)	30
9. Test Equipment Set-Up, Ventilation Tests, Open Circuit Air Helmet	33
10. Manned Subjective Dives, Open Circuit Air Helmets	45
11. Test Equipment Set-Up, Mixed Gas Helmet Compliance Tests, Helmet wet	53
12. Test Equipment Set-Up, Mixed Gas Helmet Venturi Efficiency and Exhaust Valve Tests	55
13. Sample Data Plots, Venturi Efficiency Tests	60
14. Test Equipment Set-Up, Mixed Gas Helmet Sound Level Tests	63
15. Test Equipment Set-Up, Ventilation Tests, Semi-Closed Circuit Mixed Gas Helmets	73
16. Test Equipment Set-Up, Manned Subjective Tests, Semi-Closed Circuit Mixed Gas Helmets	91

LIST OF TABLES

1. Sample Data Sheet, Open Circuit Air Sound Level Tests	29
--	----

LIST OF SYMBOLS AND TERMS

acfm	cubic feet per minute at ambient conditions
scfm	cubic feet per minute at standard conditions of 14.7 psia and 70°F, 1 scfm=26.29 slpm
ata	Atmospheres absolute
psia	lbs per sq. in. absolute
psig	lbs per sq. in. gauge
psid	lbs per sq. in. differential
psiob	lbs per sq. in. over bottom pressure
RMV	Respiratory minute volume
lpm	liters per minute at ambient conditons
alpm	liters per minute at ambient conditions, same as lpm
slpm	liters per minute at standard conditions of 14.7 psia and 0°C, 26.29 slpm = 1 scfm
cc	cubic centimeter
scc	Cubic centimeters at standard conditions of 14.7 psia and 0°C
cm H ₂ O	centimeters of water pressure
Δp	Differential pressure
free volume	Free air space within a boundary
Upper Volume Limit	The volume of a helmet system above which small increases in volume require large increases in helmet Δp relative to outside ambient pressure.
Lower Volume Limit	The volume of a helmet system below which small decreases in volume require large negative increases in helmet Δp relative to outside ambient pressure.
ΔV	Change in Volume

I. INTRODUCTION

The purpose of this protocol is to outline the general procedures and equipment to be used by EDU personnel in the evaluation of open circuit air and semi-closed circuit mixed gas diving helmets.

This protocol has been written in terms as general as possible consistent with clear understanding. It is not intended to be a step-by-step procedure which can be applied directly to the testing of a given piece of diving apparatus. Such a procedure would very quickly become out of date. It is rather intended as a detailed guide with which the Project Engineer can plan the evaluation of the apparatus to be tested. The quantities to be measured and controlled are specified for each type of test. The basic test equipment required is outlined along with the considerations governing its set-up, calibration and use. Typical test conditions and data handling requirements are also outlined for each type of test. With only a basic understanding of modern instrumentation and testing techniques a Project Engineer should be able to readily make the detailed decisions necessary to apply this protocol to a specific piece of diving apparatus.

The procedures outlined herein are concerned principally with evaluation of the functional performance of the diving apparatus (helmet and supporting equipment) being tested. No effort has been made to include specific material tests such as abrasion resistance tests for suit materials, drop and destruction tests for the helmets, etc. Those tests are very

involved, very specific and vary greatly with the system to be tested. Consequently they are considered outside the scope of this protocol. For suggestions regarding these tests, the reader is referred to references 1 and 2.

Also, no effort has been made to include specific reliability and maintainability tests. These tests are normally done during the traditional Techeval/Opeval cycles. Considerable insight into the reliability and maintainability of the apparatus tested will however be gained as a result of the tests described herein.

The tests outlined herein have been kept as simple as possible. Experience has shown that it is usually faster and more reliable to run a number of small tests where no more than 2 or 3 major variables are measured at one time than it is to try to do everything all at once. However, with skilled test operators some of the tests outlined in Section III can be combined.

Although written for helmets, this protocol can be applied with only minor modifications to mask type breathing systems as well.

II. DESCRIPTION OF THE EQUIPMENT TESTED

A. Serial Numbers

It is critically important that the piece of diving apparatus be positively identified. Most helmets and backpack scrubber units have serial numbers. Find the serial number (a call to the manufacturer may be necessary to find where to look), and record it. All data sheets used with the helmet will need the helmet serial number. If the helmet (or backpack, etc.) does not have a serial number, give it one.

B. Photographs

1. Equipment Tested

Photograph the apparatus to be tested from all appropriate angles. Usually these will include at least both sides, front and rear. Also take several photos of a diver dressed in the apparatus. If appropriate, disassemble the apparatus and take pictures of the individual components.

2. The Test Equipment

Photographs of the helmet as it is rigged for the various tests described herein are very helpful when report writing time arrives. Representative pictures should be taken of all test set-ups described, both with and without the helmet in place.

C. Physical Description

1. Material Description

A written description of the apparatus tested is

essential. It must include a description of the helmet materials of construction, valve types and sizes, face plate and port sizes, method of attachment to the diver (jocking system), communications arrangements, sealing arrangements, sealing materials, and any special features. Descriptions of CO₂ absorber assemblies must also include at least the venturi size, overbottom pressure requirements, and weight of the absorbant used. Usually the manufacturer's own literature will be sufficient. However if it is not, a description must be generated which meets the above requirements.

If possible, obtain exploded drawings from the manufacturer.

2. Size and Weight

If not provided by the manufacturer, measure the weight of the apparatus both in air and in water.

Size measurements should be taken as directed by the Project Engineer.

Measure accurately the free volume enclosed by the helmet. This can most easily be done by measuring the amount of water required to completely flood the helmet and associated equipment.

III. PERFORMANCE TESTS

A. Open Circuit Air Helmets

1. Helmet Pressure-Volume Characteristics (Compliance)

a. Background

The purpose of this test is to determine how much the pressure inside the helmet changes with respect to external ambient pressure when gas is removed from or added to the helmet. This defines the "compliance" of the helmet system. The helmet system's compliance, or the absence of it, influences very greatly the pressure variations induced in the helmet by a diver's respiration, and, therefore, the breathing impedance of the helmet. Compliance = $\Delta p / \Delta p$

This test is applicable only to neckseal helmets and other types of underwater breathing systems where the diver's chest is not enclosed by a volume of gas in free communication with the gas in the helmet interior. In cases where the chest is enclosed by a volume of gas in free communication with the helmet interior, as for instance in a helmet-dry suit combination like the USN MK 5, this test may be omitted. In those cases gas volume removed from the helmet-suit interior is normally replaced by chest expansion, and the total system volume is not influenced by the diver's respiration.

b. Quantities to be measured:

- 1) Helmet pressure re selected reference pressure
- 2) Helmet position on dummy (measure in sufficient detail so that helmet could be removed and replaced in the exact same position.)

c. Quantities to be controlled:

- 1) Amount of gas added to and withdrawn from the helmet
- 2) Neckseal Cuff Position: turned up or turned down
- 3) Helmet position on the Manikin
- 4) Manikin orientation
- 5) Helmet tested wet or dry
- 6) Temperature
- 7) Depth

e. Equipment

- 1) Specialized equipment required
 - aa. Large graduated syringe, preferably about 2 liters
 - bb. 3-way valves and plumbing as shown in Figure 1.
 - cc. Test Manikin and wet testing box
 - dd. Differential pressure transducer and transducer indicator, 1 psid
- 2) Set up the helmet and test equipment generally as shown in Figure 1. Figure 1 is intended only as a guideline, and minor modifications can be expected to accommodate the particular apparatus being tested.
- 3) The helmet should be placed on the test Manikin and jocked as nearly per manufacturer's instructions as possible. Measure the helmet position on the Manikin in sufficient detail so that it can be exactly reproduced.
- 4) The helmet supply and exhaust valves should be closed, and if necessary sealed. All Manikin openings except the openings to the syringe and pressure transducer must also be closed, and if necessary sealed. Leaks

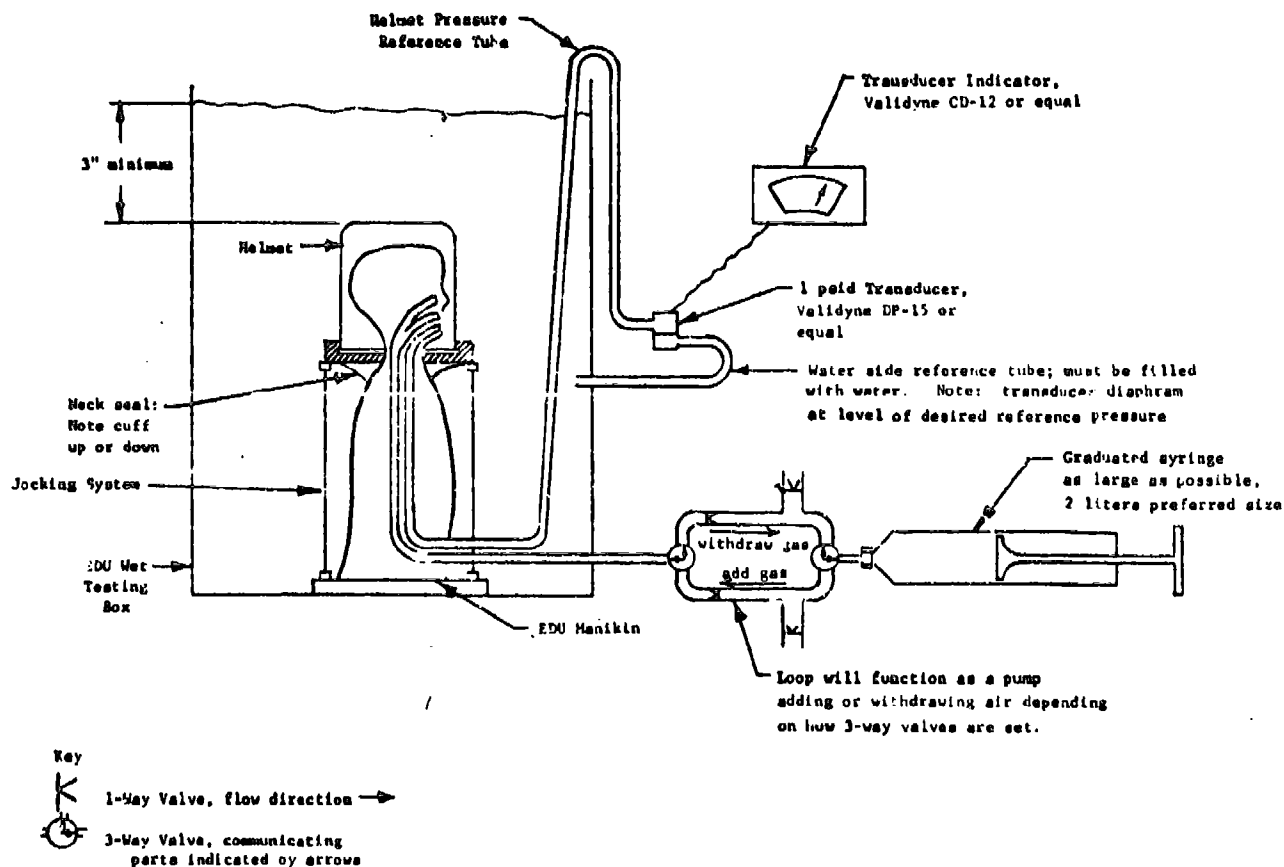


Figure 1
Test Equipment Set-Up, Open Circuit Air Helmet Compliance Tests, Helmet Wet.
For Dry Tests, Helmet & Manikin need not be inside the Wet Testing Box.

may invalidate the test. If necessary, augment the seal between the helmet neckseal and the Manikin's neck with tape (Ordnance Tape, Duct Tape or Band-AidTM Skin Tape work well), but be careful not to restrict the movement of the neckseal any more than necessary. Leaks can be checked for by adding 20 cm H₂O pressure to the helmet and observing the rate of decay. A system with a pressure decay of less than 1 cm H₂O per 15 seconds at 20 cm H₂O pressure can be considered leak-tight for this test.

- 5) The transducer line to the helmet and the syringe line must not be the same port.
- 6) The reference pressure for the transducer may be any convenient pressure, as long as the pressure used is recorded. Hydrostatic pressure at the level of the Manikin's 7th cervical vertebra, at the level of the centerline of the helmet exhaust valve, at the level of the centerline of the Manikin's mouth (as shown in Figure 1) or at any other appropriate level may be used. The Project Officer should determine ahead of time which reference pressure is to be used. See EDU Report 19-73 for information on reference pressures.

e. Calibration

Calibrate the transducer and transducer indicator against a water or mercury manometer prior to each major test.

Recheck calibration at the end of the test.

f. Test conditions and General Procedures

- 1) The helmet should be tested first dry, then wet. When tested dry, the helmet will have essentially the same compliance in all orientations. When tested wet, it will exhibit different compliance characteristics in different orientations with respect to the pull of gravity. Normally it will be sufficient to test the helmet only in the head-up vertical position shown in Figure 1. However, if ventilation tests (Section III. A. 4) are to be run in positions other than the head-up vertical, compliance tests should be performed in those positions as well.

- 2) Normally this test will be performed only at 0 fsw and room temperature. However, the Project Engineer may order additional test conditions.
- 3) Record the free volume in the helmet (from Section II.C.2.) and associated plumbing. This is needed to correct for errors due to expansion or compression of the gas occupying that free volume.
- 4) With the helmet dry and at zero Δp , add 100 cc air, record the helmet Δp indicated and return to zero Δp . Now from the zero Δp volume again, add 200 cc air, record the helmet Δp indicated and return to zero Δp . Continue this process until the upper volume limit of the helmet system is reached. The upper volume limit is that volume above which small increases in volume require very large Δp increases. Now proceed to the lower volume limit in the exact same fashion: withdrawing 100 cc air from the zero Δp volume, recording the helmet Δp , returning to zero Δp , withdrawing 200 cc air etc. Repeat 2 more times. If you did not get reproducible results, you have a major leak somewhere; fix it and try again.
- 5) Fill the test box with water to a level at least 3 inches over the top of the helmet, and repeat 4. above. Take care during the filling process and the testing process not to draw water inadvertently into the helmet.

g. Data Handling

- 1) All results are to be recorded on a chart similar to Figure 2. Note it is the Project Engineer's responsibility to correct for errors due to compression or expansion of the gas in the helmet and Manikin plumbing. At 1 ata the error is 1 scc volume/cm H_2O pressure/liter of free volume.

- 2) For each test run calibration records for each instrument calibrated must be made, clearly annotated, and attached to the data generated by each respective instrument during the runs to which the calibration record applies. This applies in particular to instruments that generate written records such as the strip chart recorders and X-Y plotter.
- 3) The Project Engineer or his representative should keep a daily log of all significant events.

2. Air Supply System and Exhaust Valve Tests

a. Background

The purpose of these tests is to determine the performance characteristics of the helmet air supply system and the helmet exhaust valve. The air supply system is considered to consist of the umbilical, non-return valve, air control valve, helmet interior plumbing and silencers.

b. Quantities to be Measured

- 1) Helmet flow rate
- 2) Helmet pressure re the selected reference pressure
- 3) Helmet gas temperature
- 4) Over bottom pressure at the inlet to the helmet non-return valve. (Gauge #1, Fig. 3)

c. Quantities to be Controlled

- 1) Umbilical size and length
- 2) Supply overbottom pressure
- 3) Depth
- 4) Air Control Valve Position
- 5) Exhaust Valve Position
- 6) Gas media

d. Equipment

- 1) Specialized equipment required

aa. Blank plate for the bottom of the helmet with provision for a pressure tap and thermistor.

- bb. Porthole blanks with reach rods or flexible shafts tailored to the helmet to be tested, 2 required.
 - cc. Flowmeters (2), approximate sizes, 3 and 12 scfm air at 70°F and 14.7 psia with a 300 psig minimum working pressure.
 - dd. Differential pressure transducer, ± 5 psid, and associated equipment.
 - ee. Thermistor and read-out unit.
 - ff. Wet testing box.
- 2) Set up the test equipment generally as shown in Figure 3. Figure 3 is intended only as a guide, and minor equipment modifications can be expected to accommodate the particular apparatus under test.
 - 3) Determine how much umbilical is appropriate to the depths to be tested and install it as shown in Figure 3.
 - 4) The Δp transducer should be set up to monitor the pressure differential between the helmet interior and the hydrostatic pressure at the exhaust valve centerline (chamber ambient pressure when helmet is tested dry).
 - 5) No remote actuation of the "chin button", if the helmet has one, is normally considered necessary. However, if desired, this can be accomplished with a third mechanical linkage such as a reach rod or a small pneumatic actuator.
 - 6) Install markings around the reach rod handles so that helmet air control and exhaust valve positions can be quickly and accurately reproduced.
 - 7) Test all equipment for free operation. Test for leaks. Repair and/or adjust as required. Leaks in the air supply system downstream from the flowmeters or in the helmet-to-test plate seal can invalidate the test.

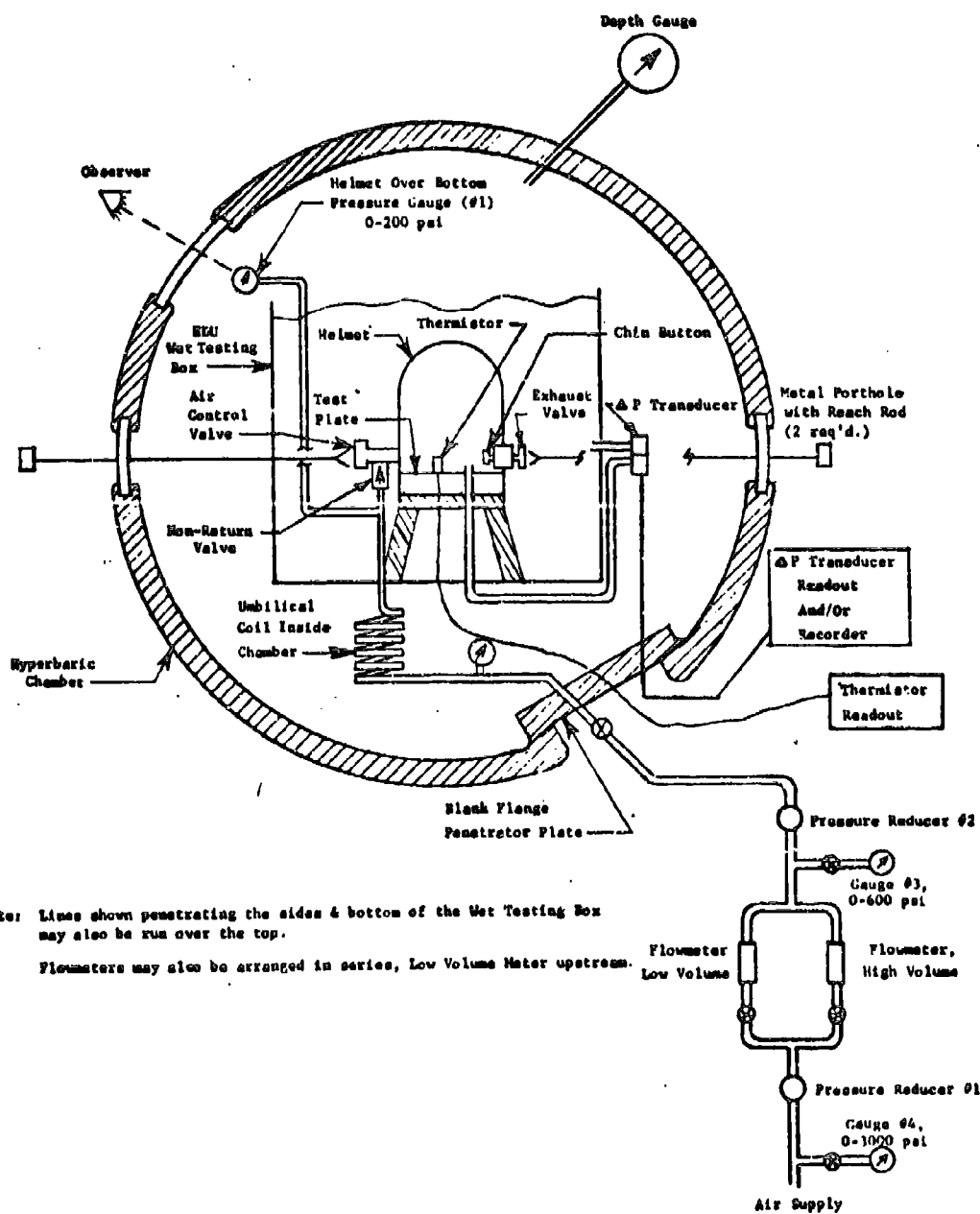


Figure 3
Test Equipment Set-up, Air Supply System & Exhaust Valve Tests

e. Calibration

- 1) Calibrate all instruments immediately prior to each major test. Re-check calibrations at the conclusion of the test.
- 2) The transducer should be calibrated against a water or mercury manometer; the thermistor against 32°F water and room temperature.
- 3) The flowmeter and gauges normally do not need daily calibration.

f. Test Conditions

The test conditions to be covered will vary with the apparatus to be tested and with the degree of testing required. The Project Engineer should determine the conditions to be tested prior to commencing the test. Typical conditions for a complete test of an open circuit air helmet follow:

Supply Pressure (Measured on Gauge #2 in Figure 3)	50 psiob, 0-120 fsw 100 psiob, 121-250 fsw
Air Control Valve Position	1/8, 1/4, 3/8, 1/2, 3/4, 1, 1-1/2, 2 turns open and full open
Exhaust Valve Position	Closed, 1/4, 1/2, 3/4 and Full Open
Depth	0, 50, 100, 150, 200, 250 fsw
Gas Media	Air
Umbilical	400' to 600' of 1/2" I.D. standard deep sea diving hose.

The large number of low air control valve settings is due to the fact that most helmet air control valves are passing their full flow capacity by the time they are 1 full turn open.

g. General Procedures

- 1) Test all of the conditions of possible interest with the helmet dry and on the surface. Get a feel for how the air control and exhaust valves operate and the effects of given valve openings. Leak check and de-bug the test equipment as required.
- 2) Repeat 1) with the helmet submerged. Maintain a minimum of 3" of water over the top of the helmet, more if the helmet has a top exhaust on the exhaust valve (ex. USN MK 5 HeO₂ Helmet).
- 3) Test the helmet under pressure, wet and/or dry on the test conditions designated by the Project Engineer.
- 4) Repeat 25 to 50% of the test readings taken on descent. This checks for reproducibility of the data.
- 5) Repeat 3) and 4) as many times as required to obtain good confidence in the data.

h. Data Handling

- 1) Record at each test condition all measured and controlled quantities on a pre-made data sheet. Carefully annotate all strip chart recordings or other permanent data records so that the data can be identified.
- 2) Plot the recorded data as directed by the Project Engineer.
- 3) Figures 4 and 5 show some sample graphs.

- 4) For each test run calibration records for each instrument calibrated must be made, clearly annotated, and attached to the data generated by each respective instrument during the runs to which the calibration record applies. This applies in particular to instruments that generate written records such as the strip chart recorders and X-Y plotter.
- 5) The Project Engineer or his representative should keep a daily log of all significant events.

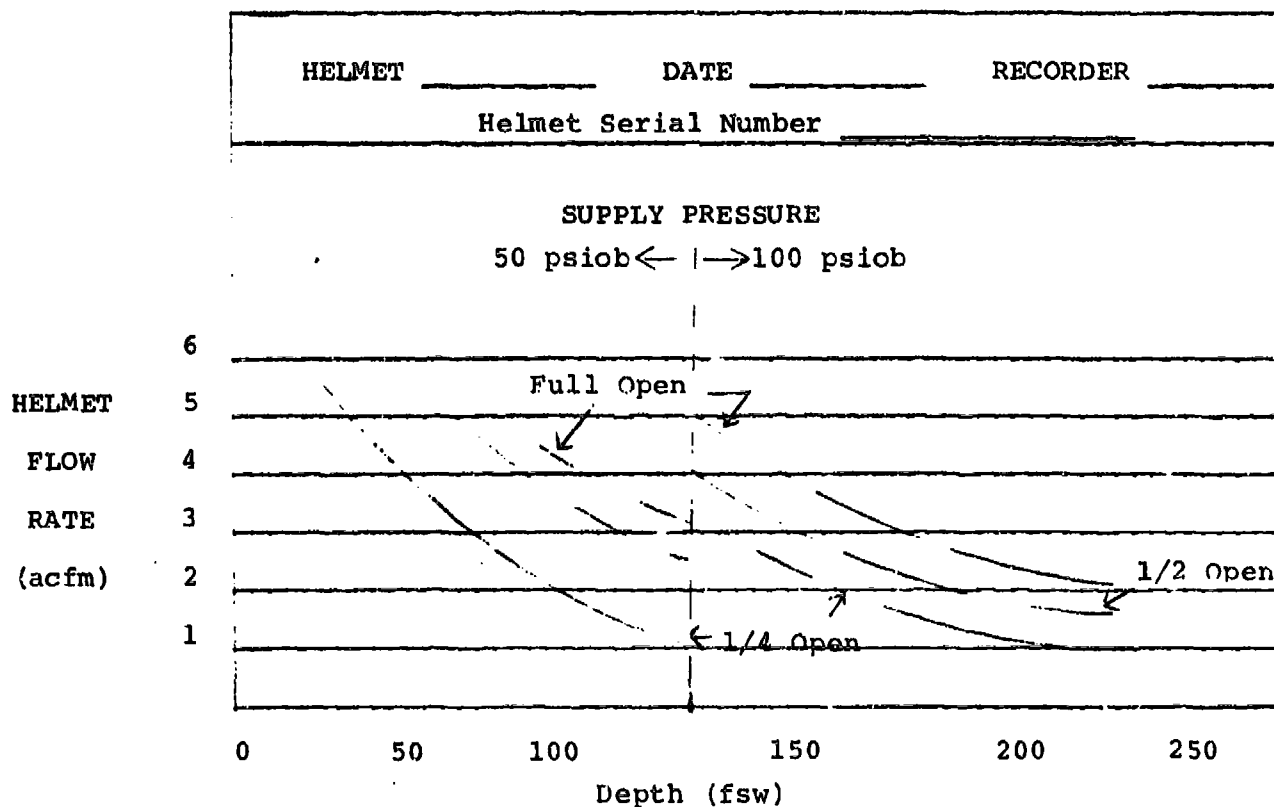


Figure 4

Sample Graph, Helmet Flow Rate Versus Depth and Air Control Valve Position

Helmet Δp
relative to
hydrostatic
pressure at
exhaust valve
centerline
(cm H₂O)

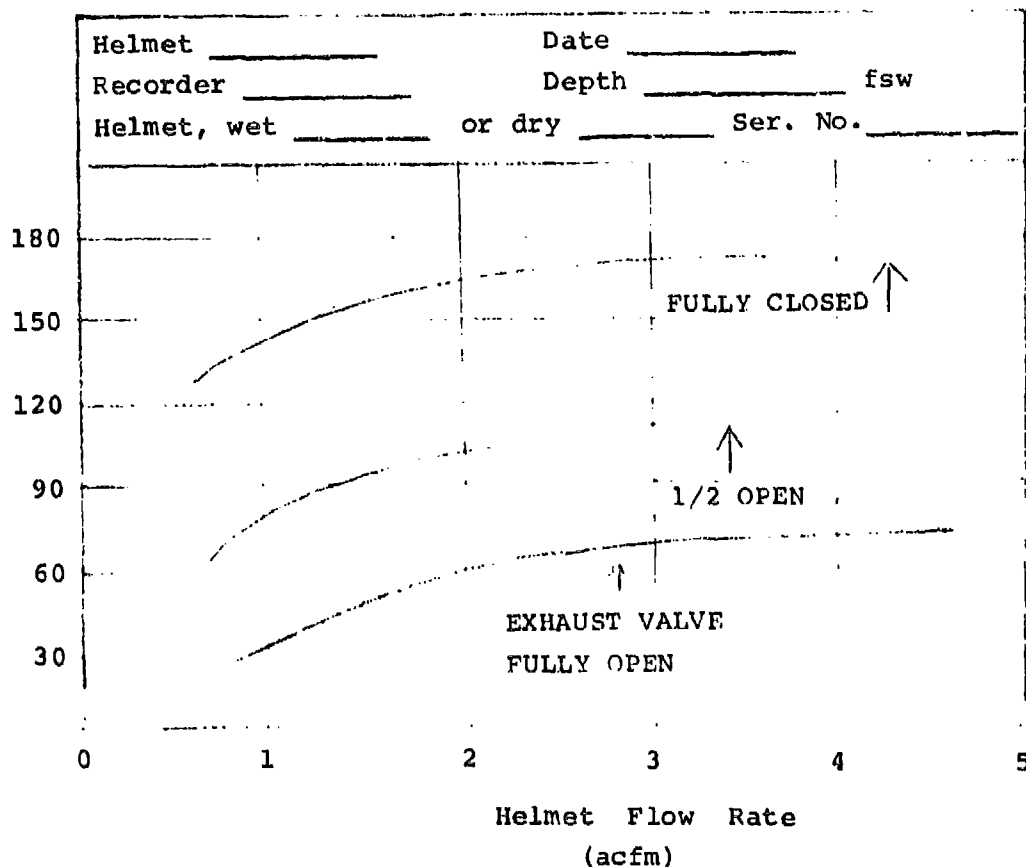


Figure 5

Sample Graph, Helmet Pressure Versus Helmet Flow Rate
and Exhaust Valve Position at a Selected Depth.

3. Sound Level Tests, Open Circuit Air

a. Background

The purpose of these tests is to measure the sound levels produced in the helmet under the conditions (depth, helmet flow rate, supply pressure, etc.) of normal diving operations, and to determine the hazard that they represent to the diver. The helmet flow rate data accumulated during these tests can and should also be used as a check on the flow rates measured under Section III. A. 2.

Experience so far has indicated that the sound levels existing in an open circuit air helmet when it is tested dry are usually little different from those when it is tested wet (EDU reports 4-73, 7-73, 11-73). However, this is not always so. It is usually, however, acceptable to do most of the helmet sound level measurements with it dry, and then do only spot checks with it submerged. This is done because wet sound level testing poses substantial risks to the sound level equipment due to shorted wires, flooded microphones, etc. Also it is advisable to perform the wet sound level tests in as large a body of water as possible to minimize possible reverberations, interaction of surface bubble noise, etc. and challenges by critics citing all of the foregoing "contaminating influences". This usually necessitates testing the helmet in one of EDU's wetpots where reach rods and, therefore, external control of the helmet valves, are not practical.

b. Quantities to be Measured

- 1) Sound pressure levels at both diver ear positions, broadband and octave band levels.
- 2) Helmet pressure
- 3) Helmet gas temperature
- 4) Overbottom pressure at inlet to helmet non-return valve (Gauge #1, Figure 6)

c. Quantities to be Controlled

- 1) Depth
- 2) Supply overbottom pressure
- 3) Helmet flow rate
- 4) Exhaust valve position
- 5) Position of helmet on test manikin. (Measure in sufficient detail so helmet could be removed and replaced in the exact same positions)
- 6) Manikin orientation
- 7) Helmet condition: wet or dry
- 8) Extranecus noise sources
- 9) Gas Media
- 10) Umbilical size and length

d. Equipment

- 1) Specialized equipment required

- aa. Accoustical testing manikin; EDU manikin, CBS Accoustical Manikin, or equal.
 - bb. Porthole blanks with reach rods or flexible shafts tailored to the helmet to be tested. One each for the air control and exhaust valves.
 - cc. Flowmeters (2), approximate sizes, 3 and 12 scfm air at 70°F and 14.7 psia with a 300 psig minimum working pressure.
 - dd. Differential pressure transducer, approximate range ± 5 psid, and associated signal conditions and recorders.
 - ee. Thermistor and read-out unit
 - ff. Sound level equipment as per Figure 6 or equal.
- 2) Set up the test equipment as shown in Figure 6. If both ear positions are to be tested at the same time, the sound level equipment shown will need to be duplicated.
 - 3) Determine how much umbilical is appropriate to the depths to be tested and install it as shown in Figure 6.
 - 4) Install markings around the reach rod handles so that helmet air control and exhaust valve positions can be quickly and accurately reproduced.
 - 5) If a neckseal helmet is to be tested as shown in Figure 6, augment the seal between the neckseal and the manikin's neck with tape (Band-AidTM Skin Tape,

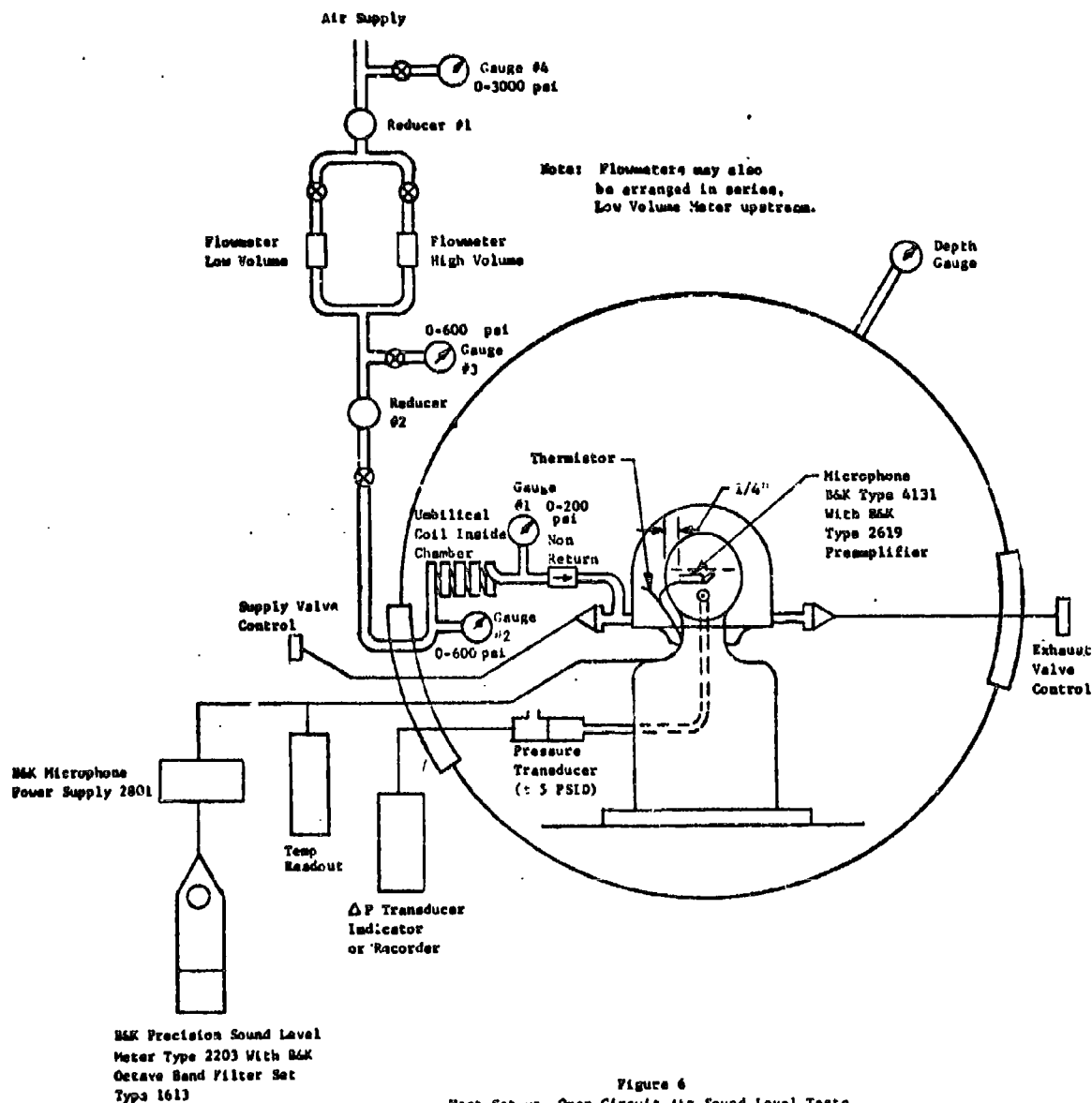


Figure 6
Test Set-up, Open Circuit Air Sound Level Tests
Helmet Shown Dry With a Neck Seal.

Duct Tape, Ordnance Tape all will work). If the helmet is to be tested with a full suit (as for example a USN MK 5 helmet), select a suit with cuffs, place the manikin inside the suit and bring the necessary wires, etc. out through one of the sleeves. Securely restrain the bottom of the suit so that it does not inflate. One of the best ways to do this is to simply roll it up and tie it off. Close the sleeves with flat clamps taking care not to damage the microphone and thermistor wires.

- 6) Test all equipment for free and normal operation. Test for leaks. Repair and/or adjust as required. Leaks in the air supply system downstream from the flowmeters or in the neckseal-to-manikin seal can invalidate the flow rate data. Leaks in the helmet, neckseal (or suit) and through the manikin will tend to falsely increase the measured sound levels.

e. Calibration

- 1) Calibrate all adjustable instruments immediately prior to each major test. Re-check calibrations at the conclusion of the test.
- 2) The transducer should be calibrated against a water or mercury manometer; the thermistor against 32°F water and room temperature.
- 3) The flowmeter and gauges normally do not need daily calibration.
- 4) The microphone and sound level meter should be calibrated with a B&K Type 4230 Sound Level Calibrator or equal.

f. Test Conditions

The test conditions to be covered will vary with the apparatus to be tested and with the degree of testing required. The Project Engineer should determine the conditions to be tested prior to commencing the test. Typical conditions for a complete test of an open circuit air helmet follow:

1. Helmet Dry

Depth	0, 50, 100, 150, 200, 250 fsw
Supply Pressure (Measured on Gauge #2, Fig. 6)	50 psiob, 0-120fsw 100 psiob, 121-250 fsw
Helmet Flow Rate	3 acfm, 4.5 acfm, max. flow possible (air control valve fully open)
Exhaust Valve Position	Fully Open, Fully Closed
Position of Helmet on manikin	Normally Jocked Position
Manikin Orientation	Head-up Vertical
Gas Media	Air
Umbilical	400' to 600' of 1/2" I.D. standard deep sea diving hose

2. Helmet Wet

All test conditions are the same as for the helmet dry tests except:

Helmet Flow Rate

Max. flow, other
flows as directed
by Project Engineer

Helmet Exhaust Valve

Fully Closed

Helmet exhaust valve settings of less than fully closed should be used in wet tests only with great care. Lower exhaust valve settings decrease the helmet Δp relative to outside water pressure and increase the chances of flooding the helmet and ruining the microphones.

g. General Procedures

- 1) Measure the chamber background noise. Background noise from all sources, room noise, electrical noise, etc. should read less than 70 dB in all octave bands. Slightly higher levels can, however, be tolerated in the 31.5, 63 and 125 Hz center frequency octave bands.
- 2) Test all of the conditions of interest with the helmet dry and on the surface. Get a feel for how the air control and exhaust valves operate and the effects of given valve openings. Leak check and de-bug the test equipment as required.
- 3) Test the helmet under pressure, dry as shown in Figure 6. Test under the test conditions designated by the Project Engineer. The best sequence to follow is usually to do all of the test conditions at 0 fsw, then 50 fsw, etc. on down to 250 fsw.
- 4) During ascent from 250 fsw (or max. depth) repeat 25 to 50% of the test readings taken during descent. This checks for reproducibility of the data.

- 5) Once the dry tests in 1) through 3) above are completed, run the wet tests. This will require either the wet testing box or the wetpot.
- 6) Repeat 2), 3) and 4) above as many times as required to obtain good confidence in the data obtained.
- 7) Run a dry test, 0 fsw only should be sufficient, with the helmet removed 1/2" off its neckring or breastplate. This allows the air to escape without going out the exhaust valve, and it should allow a determination of how much, if any, of the measured helmet sound levels are due to exhaust valve noise vice air supply system noise. Normally the exhaust valve makes only a minor contribution to the total helmet noise levels

h. Data Handling

- 1) Record at each test condition all measured and controlled quantities on a pre-made data sheet. Carefully annotate all strip chart recordings or other permanent data records so that the data can be identified.
- 2) Correct the octave band sound pressure level readings from the sound level meter for the microphone sensitivity loss under increased pressure. See the microphone manual or Reference A for the octave band correction factors.
- 3) From the corrected octave band sound pressure levels, determine the equivalent A-weighted sound pressure level from Figure 7. Determine the maximum daily exposure from Figure 8. Consult References 2 and 3 for further information.
- 4) NOTE: The dBA scale on the sound level meter cannot normally be used except at 0 fsw

due to the uneven effect increasing ambient pressure has on the frequency response characteristics of the microphone. See Reference A and NAVXDIVINGU Reports 10-73 and 12-73 for more information on this effect.

- 5) Table 1 represents a typical data sheet.
- 6) For each test run calibration records for each instrument calibrated must be made, clearly annotated, and attached to the data generated by each respective instrument during the runs to which the calibration record applies. This applies in particular to instruments that generate written records such as the strip chart recorders and X-Y plotter.
- 7) The Project Engineer or his representative should keep a daily log of all significant events.

Sample Data Sheet, Open Circuit Air Sound Level Tests

[illegible]

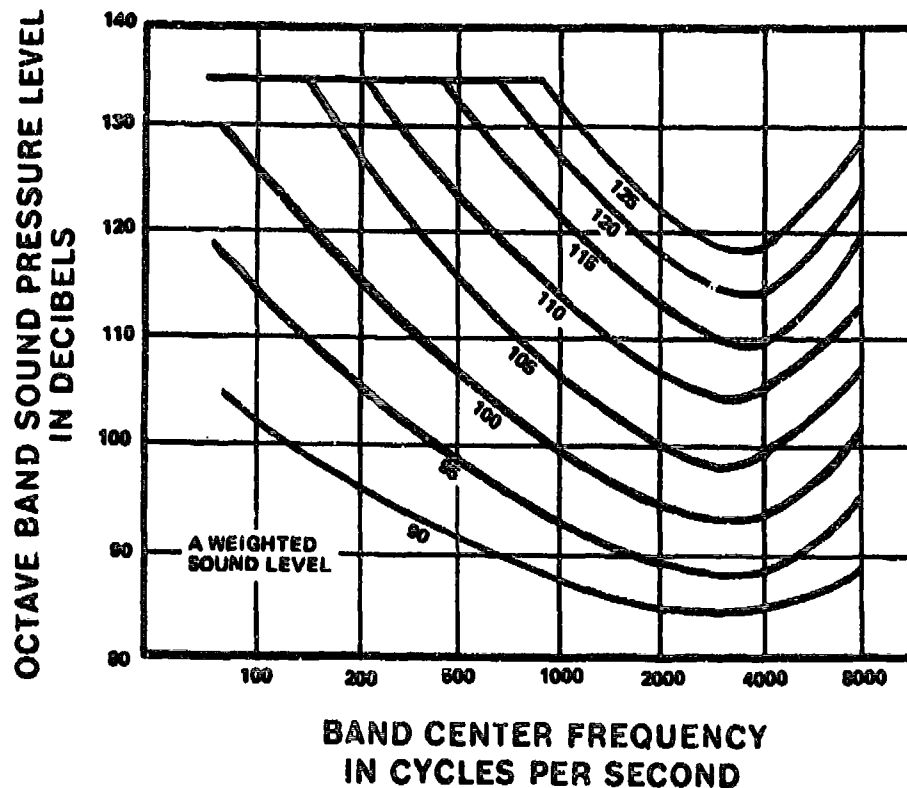


Fig. 7. Equivalent A-Weighted Sound Level Contours. Octave Band Sound Pressure Levels May Be Converted to the Equivalent A-Weighted Sound Level by Plotting Them on This Graph and Noting the A-Weighted Sound Level Corresponding to the Point of Highest Penetration into the Sound Level Contours (2).

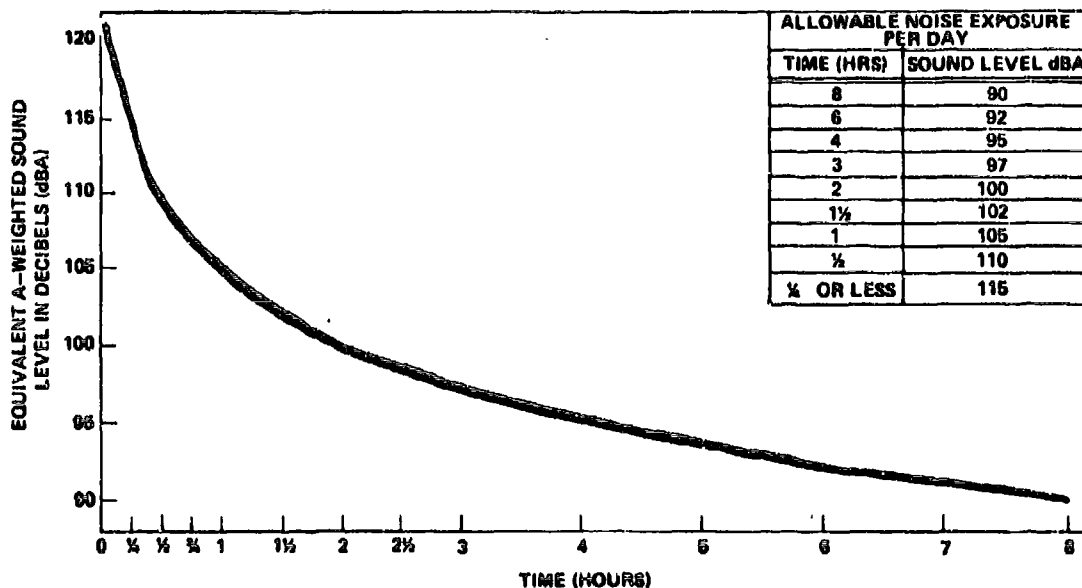


Figure 8
Currently Accepted Daily Noise Exposure Limits (2) (3).

4. Ventilation Tests, Open Circuit Air

a. Background

The purpose of these tests is to determine the ventilation characteristics of the helmet when used on open circuit air. The variables of primary interest are the helmet flow rate, the pCO_2 levels in the helmet and in the manikin's inspired air and the pressure variations induced in the helmet by the manikin's respiration.

The performance of the helmet air control and exhaust valves during these tests can and should be used as a check on the results obtained in Sections III. A. 2 and III. A. 3. Also when the helmet is tested with a neckseal, the pressure variations induced in the helmet by the manikin's respiration should be predictable from the helmet compliance results of Section III. A. 1 and the exhaust valve performance results of Section III. A. 2.

b. Quantities to be Measured

- 1) PCO_2 levels at the following locations.
 - aa. Inhalation mixing box (inhaled pCO_2 level, CO_2 #1, Figure 9)
 - bb. Exhalation mixing box (exhaled pCO_2 level, CO_2 #2, Figure 9)
 - cc. Inlet to helmet exhaust valve (CO_2 #2, Figure 9)
 - dd. Any other location(s) selected by the Project Engineer.

- 2) Helmet pressure relative to hydrostatic pressure at the selected level.
- 3) Helmet gas temperature.
- 4) Air control valve position.
- 5) Overbottom pressure at the inlet to the helmet non-return valve. (Gauge #1, Figure 9)
- 6) Relative humidity of inspired air.

c. Quantities to be Controlled

- 1) Depth
- 2) Supply overbottom pressure (Gauge #2, Figure 9)
- 3) Helmet flow rate
- 4) Exhaust valve position
- 5) Position of helmet on test manikin. Measure in sufficient detail so that helmet could be removed and replaced in exactly the same position
- 6) Manikin orientation
- 7) Helmet condition: wet
- 8) Gas media
- 9) Umbilical size and length
- 10) Manikin respiratory parameters
 - aa. CO₂ addition rate
 - bb. Breathing rate

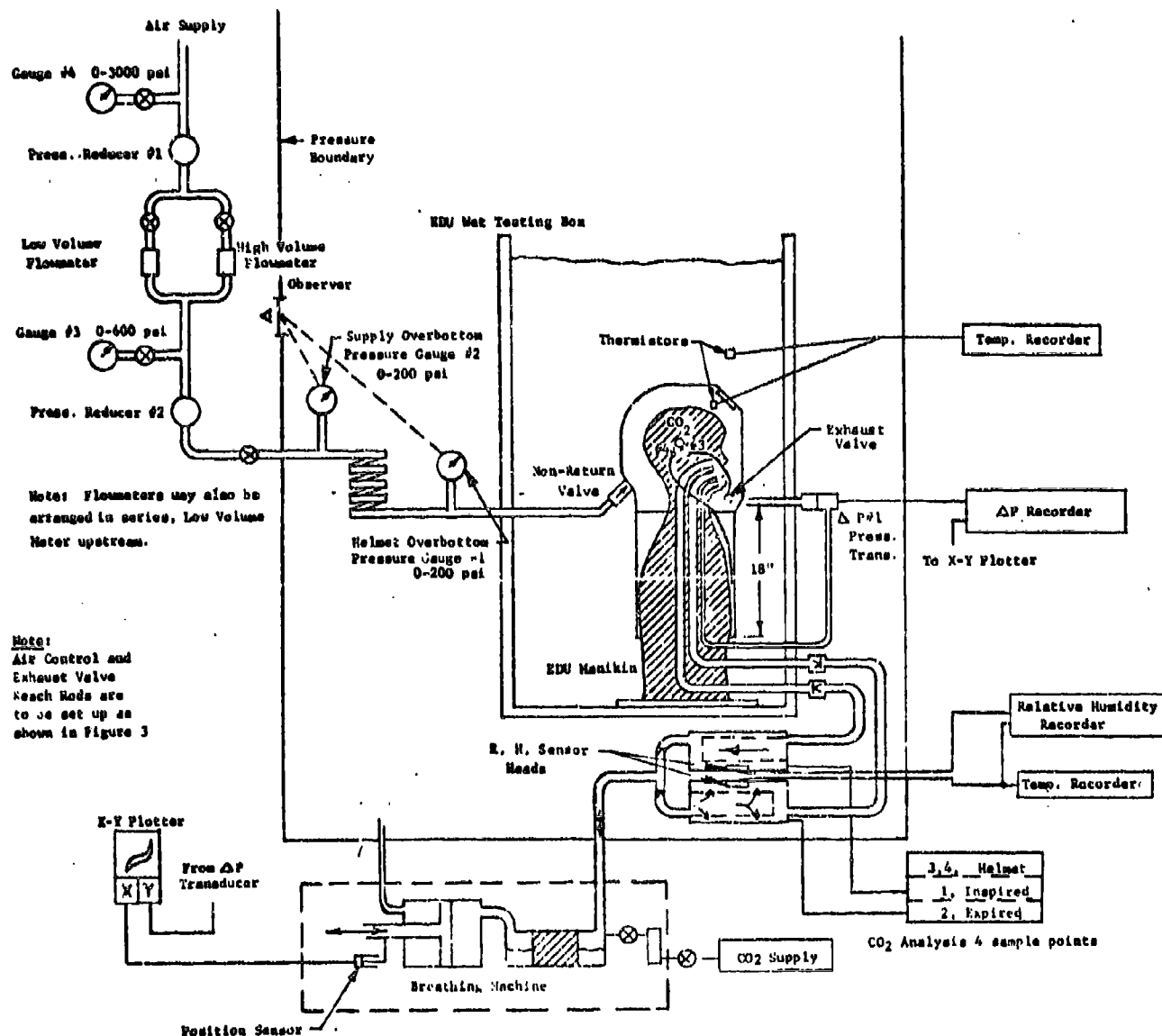


Figure 9
Test Equipment Set-up, Ventilation
Test, Open Circuit Air Helmets

- cc. Tidal volume
 - dd. Volume-time waveform
 - ee. Exhaled relative humidity
 - ff. Exhaled gas temperature
- d. Equipment Set-up
- 1) Specialized equipment required
 - aa. EDU manikin with double treacheas, one for inhalation, one for exhalation. Manikin should also have provisions for monitoring the pressure and temperature inside the helmet and for obtaining up to 4 gas samples from selected locations within the helmet and neckseal or suit.
 - bb. Porthole blanks with reach rods or flexible shafts tailored to the helmet to be tested. One each for the air control and exhaust valves.
 - cc. Flowmeters (2), approximate sizes, 3 and 12 scfm air at 70°F and 14.7 psia with a 300 psig minimum working pressure.
 - dd. Differential pressure transducer, approximate range ± 5 psid, and associated signal conditions and recorders.
 - ee. Thermistor and read-out unit
 - ff. Breathing machine with inhalation and exhalation mixing chambers.
 - gg. At least 2 CO₂ analysers, one with a range of 0 to 0.5% by volume or 0 to 1.0% by volume, one with a range of 0 to 6% by volume. CO₂

level #2 (Figure 9, exhalation mixing box) can be expected to run between 4 to 6% S.E. All other CO₂ levels can be expected to run between 1 to 3% S.E.

- 2) Set up the equipment generally as shown in Figure 9. Figure 9 is intended only as a guide, and minor equipment modifications can be expected to accommodate the particular apparatus under test.
- 3) Determine how much umbilical is appropriate to the depths to be tested and install it as shown in Figure 9.
- 4) The Δp transducer should be set up to monitor the pressure differential between the helmet interior and the hydrostatic pressure at the exhaust valve centerline (chamber ambient pressure if helmet is tested dry), or the level of the manikin's 7th cervical vertebra. Use a different reference pressure if so directed by EDU report 19-73.
- 5) Install markings around the reach rod handles so that helmet air control and exhaust valve positions can be quickly and accurately reproduced.
- 6) The internal free volume of all inhalation plumbing components must not be greater than 10 liters. The internal free volume of all exhalation plumbing components must likewise be less than 10 liters. The internal free volume of components used for both inhalation and exhalation is to be charged against both 10 liter limits. 10 liters free volume is the most free volume that can be tolerated without introducing excessive errors due to pneumatic compliance (gas compressability). See EDU Report 20-73, Section III for more details.
- 7) Total mechanical compliance (hose stretch, etc.) of the breathing loop plumbing must be kept below .05 liter per 20 cm H₂O pressure change.

- 8) Water depth over the top of the helmet should be at least 6 inches.
- 9) If the helmet is to be tested with a dry suit, cut a suit at approximately the waist level and fasten to the manikin with a band clamp and tape at a level 18" below the exhaust valve centerline as shown in Figure 9. The simulation will not be complete with this equipment set-up because a diver when he inhales normally makes up the air volume he inhaled from the helmet-suit combination by chest expansion. Thus in reality the total suit volume remains essentially uninfluenced by the diver's respiration whereas with the set-up shown in Figure 9 it will be influenced slightly. The errors introduced by this deviation from actual conditions are normally negligible. If a better simulation is desired, a counterlung may be placed around the manikin's chest and plumbed to the reference side of the breathing machine piston. This, however, must be done with great care so as not to inadvertently cause a loss of free communication between chamber ambient pressure and the pressure on the reference side of the breathing machine piston. This procedure is, therefore, not recommended unless absolutely essential to the validity of the test to be run.
- 10) If the helmet is to be tested with a neckseal, be certain that the neckseal fits very snugly to the manikin's neck. If helmet flooding or neckseal leakage is still a problem, augment the neckseal-to-manikin neck seal with tape (Band-AidTM Skin Tape, Duct Tape, Ordnance Tape work well), but be careful not to restrict the movement of the neckseal any more than necessary.
- 11) Set up the X-Y plotter so that it makes plots of helmet pressure versus inspired-expired volume. Plots of helmet pressure versus inspiratory-expiratory flow rates may also be useful.

- 12) All CO₂ sampling lines should have small water traps.
- 13) All breathing loop components should have an I.D. of not less than 3/4". The lengths of the hoses between the SCUBA mouthpiece and the manikin are not critical and may be as long as required so long as the 10 liter free volume limit of 6) above is observed. The lengths of the hoses and pipes between the SCUBA mouthbit and the breathing machine are important and should be kept as short as possible with reasonable effort.
- 14) The output of the Δp transducer must be continuously recorded. Continuous recording of the outputs of the CO₂ analysers is highly recommended. The output of the Δp transducer varies so rapidly with time that it cannot be read from a panel meter. The outputs of the CO₂ analysers will vary enough with time to make accurate readings from a panel meter difficult.
- 15) Test all equipment for free operation. Test for leaks. Repair and/or adjust as required. Leaks in the air supply system downstream can invalidate the flow rate data. Leaks in the breathing loop plumbing can invalidate the CO₂ data. The breathing loop plumbing can be considered leak tight if, with the manikin's mouth sealed or corked shut, the system will hold both a 20 cm H₂O pressure and a 20 cm H₂O vacuum with a pressure (vacuum) decay rate of less than 1 cm H₂O per 10 seconds at 20 cm H₂O pressure (vacuum).

e. Calibration

- 1) Calibrate all adjustable instruments immediately prior to each major test. Re-check calibrations at the conclusion of the test.

- 2) The transducer should be calibrated against a water or mercury manometer; the thermistor against 32°F water and room temperature.
- 3) The flowmeter and gauges normally do not need daily calibration.
- 4) The CO₂ analysers should be calibrated against at least 3 known gases each: full scale, zero and mid-range CO₂ concentrations. If the CO₂ analyser calibrations are non-linear several more calibration points and a graphical calibration record will be required.
- 5) Calibrate the X-Y plotter axes prior to each test. Re-check at the conclusion of each test. Y axis should read helmet pressure; the X axis, inspired-expired volume.

f. Test Conditions

The test conditions to be covered will vary with the apparatus to be tested and with the degree of testing required. The Project Engineer should determine the conditions to be tested prior to commencing the test. Typical conditions for a complete test of an open circuit air helmet follow:

Depth	0, 50, 100, 150, 200, 250 fsw
Supply Pressure (Measured on Gauge #2, Fig. 9)	50 psiob, 0-120 fsw 100 psiob, 121-250 fsw

Helmet Flow Rate	3 acfm, 4.5 acfm, max. flow possible (air control valve fully open)
Exhaust Valve Position	Fully Closed, 1/4, 1/2, 3/4 Fully Open
Position of Helmet on manikin	Normally Jocked Position
Manikin Orientation	Head-up Vertical, other orientations may also warrant testing, especially the face- down horizontal position.
Gas Media	Air
Umbilical	400' to 600' of 1/2" I.D. standard deep sea diving hose
Helmet Condition	Wet
Manikin Respiratory Parameters*	
CO ₂ Addition Rate	.04 X RMV slpm (ex. 1.6 slpm at 40 lpm RMV)
Breathing Rate	15, 20 and 25 breaths per minute
Tidal Volume	1.5, 2.0 and 2.5 liters per breath respectively at breathing rates of 15, 20 and 25 bpm.

Volume-Time Waveform

Flattened Sinusoid
with an exhalation to
inhalation time ratio
of 1.1 to 1.0 and a
ratio of peak flow
to minute volume of
2.7.

Exhaled Gas Temperature** 97± 2°F

Exhaled Relative Humidity** Saturated at 97°F

* Parameters recommended by EDU Report 19-73

** Relatively unimportant parameters. These can
be ignored without jeopardizing the validity of
most tests.

g. General Procedures

- 1) These tests are normally done only with the helmet wet.
- 2) Test all of the conditions of interest with the helmet on the surface. Get a feel for how the air control and exhaust valves operate and the effects of given valve openings. Leak check and de-bug the test equipment as required.
- 3) Test the helmet under pressure. Test under the test conditions designated by the Project Engineer. The best sequence to follow is usually to do all of the test conditions at 0 fsw, then 50 fsw, etc. on down to 250 fsw.
- 4) During ascent from 250 fsw (or max. depth) repeat 25 to 50% of the test readings taken during descent. This checks for reproducibility of the data.

- 5) Maintain each test condition until all values stabilize. This may take as long as 15 minutes.
- 6) Repeat 3) and 4) above as many times as required to obtain good confidence in the data.

h. Data Handling

- 1) On-line cross-checking of data values is essential for this test. The best cross-check to use is simple CO_2 conservation. There are 2 checks that can be used.

aa. PCO_2 #2 - PCO_2 #1 should equal 4.0% S.E. \pm .3% S.E.

bb. Exhaust PCO_2 (% S.E.) X Helmet Flow Rate (alpm)² should approximate the CO_2 add rate. This check is reliable only in helmets tested with suits. It is not particularly good in helmets tested with neckseals. The analysis of the exhausted gas represents a time average CO_2 level and not a volume average level which is what is necessary for this cross check to be reliable. When the helmet is used with a suit, the volume and time averages can be expected to be negligibly different. When the helmet is used with a neckseal, the 2 averages can be quite different (See EDU Report 7-73, Appendix A for more details).

- 2) Record at each test condition all measured and controlled quantities on a pre-made data sheet. Carefully annotate all strip chart recordings or other permanent data records so that the data can be identified.
- 3) Plot the recorded data as directed by the Project Engineer. EDU Report 7-73, Figures 10 and 11 show possible ways of presenting the data. Tables 5 and 6 of that report likewise show possible ways of organizing

it in tabular form. If the work of breathing standards proposed by EDU Report 19-73 are adopted, a plot of the external work of breathing will also be required.

- 4) From the plots of helmet pressure versus inspired-expired volume made on the X-Y plotter, calculate the external work of breathing expended by the manikin. Compare against the .17 Kg-m/liter ventilation limit proposed by EDU Report 19-73.
- 5) For each test run calibration records for each instrument calibrated must be made, clearly annotated, and attached to the data generated by each respective instrument during the runs to which the calibration record applies. This applies in particular to instruments that generate written records such as the strip chart recorders and X-Y plotter.
- 6) The Project Engineer or his representative should keep a daily log of all significant events.

5. Manned Dives, Subjective Evaluation

a. Background

Definitive manned testing of the helmet for ventilation adequacy will be accomplished under Section III.

A. 6, Physiological Testing.

This section is concerned with essentially subjective tests to obtain a rough measure of the comfort, human engineering and mobility of the helmet. To determine those qualities accurately requires a rather large program of manned tests considered to be outside the scope of this evaluation. The tests outlined below can be accomplished quickly and relatively easily. They will provide an indication of the helmet mobility, human engineering and comfort sufficient to point out any really serious troubles that must be addressed before larger scale manned tests such as Techeval/Opeval are undertaken.

The instrumentation recommended below is relatively sparse. This is so not because of design, but rather due to the extreme difficulty of making measurements underwater on a diver who is free to move about as he chooses in a relatively large body of water; 8000 gallons in the case of an EDU wetpot.

b. Quantities to be Measured

1) Helmet flow rate

2) Helmet PCO_2 level at:

aa. Inlet to exhaust valve

bb. One other location chosen to match location #4 in the tests conducted under Section III. A. 4.

3) Helmet oxygen concentration

4) Helmet Δp relative to hydrostatic pressure at the exhaust valve centerline. If a different reference pressure was used in Section III. A. 4, then use that reference pressure instead.

5) Helmet temperature

6) Helmet air control and exhaust valve positions selected by the divers.

c. Quantities to be Controlled

1) Depth

2) Diver work tasks

3) Wetpot temperature

4) Supply overbottom pressure

5) Gas Media

d. Equipment

1) Specialized equipment required

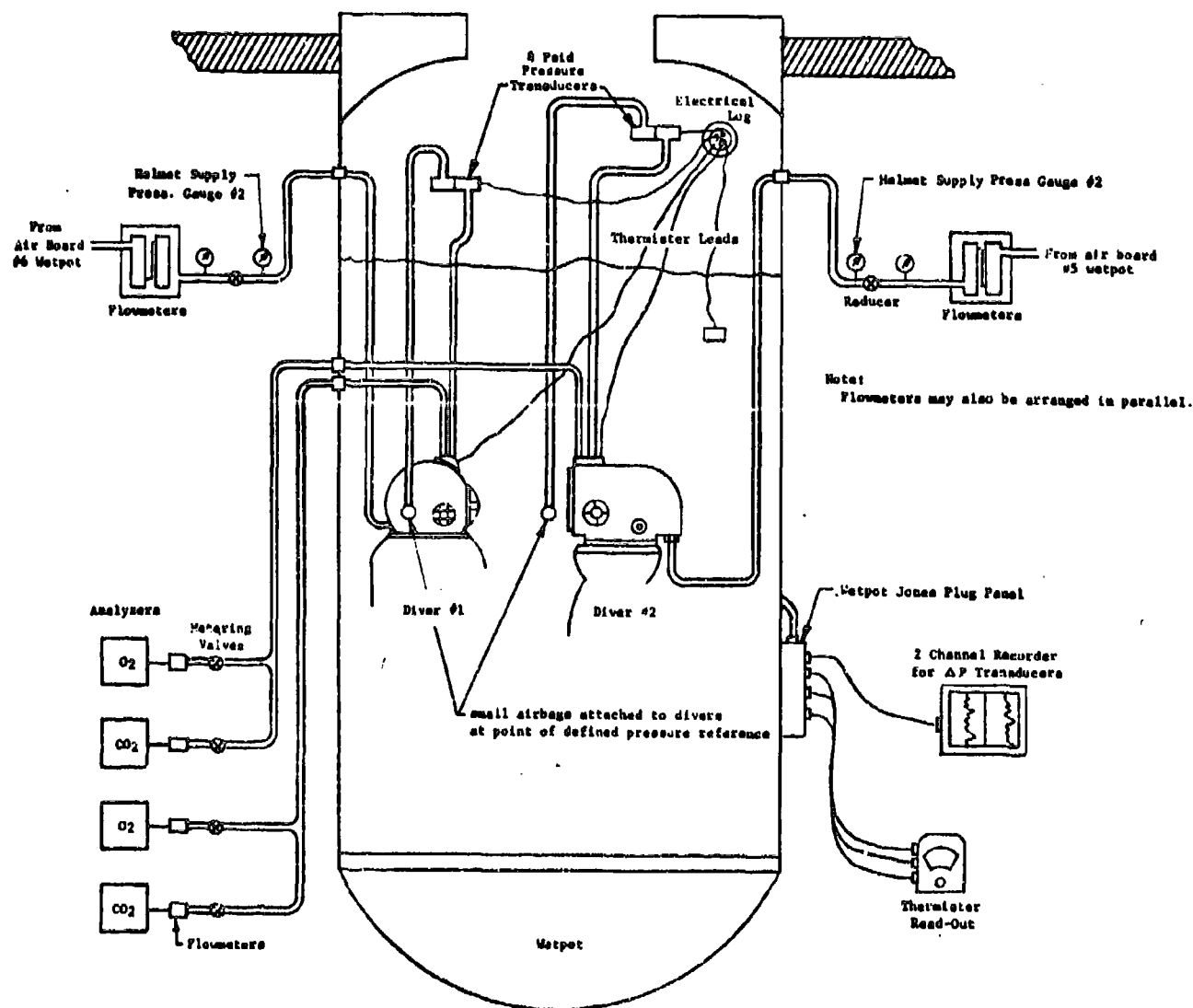


Figure 10
Test Set-up for Chamber Manned Subjective Dives, Open Circuit Air Helmets

- aa. Flowmeters, approximate sizes, 3 and 12 scfm air at 70°F and 14.7 psia with a 300 psig minimum working pressure.
 - bb. Differential pressure transducers, approximate range ± 8 psid, and associated signal conditions and recorders.
 - cc. Thermistors and read-out unit
 - dd. CO₂ analysers, 0 to 1.0% by volume range with recorders.
 - ee. Oxygen analysers, 0 to 25% by volume range, with recorders
- 2) Set up the test equipment generally as shown in Figure 10. Figure 10 is intended only as a guide, and minor equipment modifications can be expected to accommodate the particular apparatus under test.
 - 3) Determine how much umbilical is appropriate to the depths to be tested and rig it inside the chamber, coiling the excess in an out-of-the-way place. If very accurate flow rates are not required, using the full 400' to 600' of umbilical may be omitted in favor of simple short leader hoses.
 - 4) All gas sampling lines should have water traps.
 - 5) The outputs of the O₂ and CO₂ analysers should be continuously recorded. The output of the Δp transducer must be continuously recorded. Hand recordings of the Δp , O₂ and CO₂ values every 5 minutes, as is commonly done, are of little value due to often rapidly changing values. The helmet flow rates are usually sufficiently steady to permit hand recording of the flowmeter readings.

e. Calibration

- 1) Calibrate all adjustable instruments immediately prior to each major test. Re-check calibrations at the conclusion of the test.
- 2) The Δp transducers should be calibrated against a water or mercury manometer; the thermistors against 32°F water and room temperature.
- 3) The flowmeter and gauges normally do not need daily calibration.
- 4) All gas analysis instruments should be calibrated against at least 3 known gases each: full scale, zero and mid-range concentrations. If the analysers, especially the CO₂ analysers, are non-linear, several more calibration points and a graphical calibration record is required.

f. Test Conditions

The test conditions to be covered will vary with the apparatus to be tested and with the degree of testing required. The Project Engineer should determine the conditions to be tested prior to commencing the test. Typical conditions for a complete test of an open circuit air helmet follow:

Depth	0, 50, 100, 150, 200 250 fsw
Supply Pressure (Measured on Gauge #2, Fig. 10)	50 psiob, 0-120 fsw 100 psiob, 121-250 fsw

Wetpot Temperature	70°F or above (due to wetpot steel NDT considerations)
Gas Media	Air
Diver Work Tasks	See procedures subsection

g. General Procedures

- 1) For a reasonably thorough subjective evaluation at least 5 dives should be made to each depth. Always use divers who have had sufficient exposure on the helmet so that they feel familiar with its controls.
- 2) Normal U.S. Navy diving procedures are to be followed. While on the bottom the divers should alternate between 10 minute periods of "moderate" work and 5 minute rest periods. Normally the work tasks alternate between lifting a 70-pound weight (78 lbs dry) a distance of 2-1/2 feet 10 times per minute and swimming against a trapeze designed to exert a steady backward force of 6.0 lbs. For an average diver, exerting a stationary swimming force of 6.0 lbs. produces an oxygen demand of approximately 1.26 standard liters per minute (6). This is equivalent to a respiratory minute volume of approximately 30 liters per minute (7) or to swimming in SCUBA at a steady speed of approximately 0.8 knots (6) (7). An oxygen demand of 1.26 slpm results in a CO₂ production of about 1.13 slpm (8). Working against an underwater bicycle or pedal ergometer is also a suitable task.
- 3) At the conclusion of each dive, the diver should fill out the applicable portions of the Diver Equipment Subjective Analysis Questionnaire reproduced in Appendix A.
- 4) Have several divers dis-assemble and re-assemble the helmet air control and exhaust valves. Note any difficulties encountered.

h. Data Handling

- 1) Record at each test condition all measured and controlled quantities on a pre-made data sheet. Carefully annotate all strip chart recordings or other permanent data records so that the data can be identified.
- 2) Compare the CO_2 levels and helmet flow rates measured to the results of Section III. A.4. Compare the measured helmet PCO_2 and PO_2 levels with those predicted on the basis of the measured helmet flow rates and the diver CO_2 production and oxygen consumption rates expected as a result of the work tasks selected.
- 3) Tabulate and/or plot the data obtained as directed by the Project Engineer. There is usually sufficient variability in the data from these dives to make concise plotting difficult.
- 4) The Project Engineer or his representative should keep a daily log of all significant events.
- 5) For each day's test dives, calibration records must be made, clearly annotated and attached to the data generated by each respective instrument during the runs to which the calibration record applies.

6. Manned Dives, Physiological Testing

The purpose of these tests is to determine quantitatively the ability of the apparatus under test to support the physiologic and respiratory requirements of a diver at hard work. The tests are normally conducted by the EDU Medical Department.

The procedures and equipment used for these tests are still being refined. A detailed protocol covering these tests is expected to be published by the EDU Medical Department sometime in second quarter of CY 1974.

B. Semi-Closed Circuit Mixed Gas Helmets

1. Helmet Pressure-Volume Characteristics (Compliance)

a. Background

The purpose of this test is to determine how much the pressure inside the helmet changes with respect to external ambient pressure when gas is removed from or added to the helmet. This defines the "compliance" of the helmet system. The helmet system's compliance, or the absence of it, influences very greatly the pressure variations induced in the helmet by a diver's respiration, and, therefore, the breathing impedance of the helmet.

This test is applicable only to neckseal helmets and other types of underwater breathing systems where the diver's chest is not enclosed by a volume of gas in free communication with the gas in the helmet interior. In cases where the chest is enclosed by a volume of gas in free communication with the helmet interior, as for instance in a helmet-dry suit combination like the USN MK 5 HeO₂ rig, this test may be omitted. In those cases gas volume removed from the helmet-suit interior is normally replaced by chest expansion, and the total system volume is not influenced by the diver's respiration.

b. Quantities to be measured:

- 1) Helmet pressure re selected reference pressure
- 2) Helmet position on dummy (measure in sufficient detail so that helmet could be removed and replaced in the exact same position)

c. Quantities to be Controlled:

The quantities to be controlled are the same as those listed in Section III. A. 1. c.

d. Equipment

The equipment to be used is the same as that listed in Section III. A. 1. d. with the following additions:

- 1) The CO₂ removal unit (if separate from the helmet) is to be set up with the helmet and jocked as nearly per manufacturer's instructions as possible.
- 2) Be certain that the venturi control valve is secured. If the helmet has no venturi control valve, cap the gas inlet connection.
- 3) Figure 11 shows a typical test set-up.

e. Calibration

The calibration procedures are the same as those listed in Section III. A. 1. e.

f. Test Conditions and Procedures

The test conditions and procedures are the same as those listed in Section III. A. 1. f.

g. Data Handling

The data handling requirements are the same as those listed in Section III. A. 1. g.

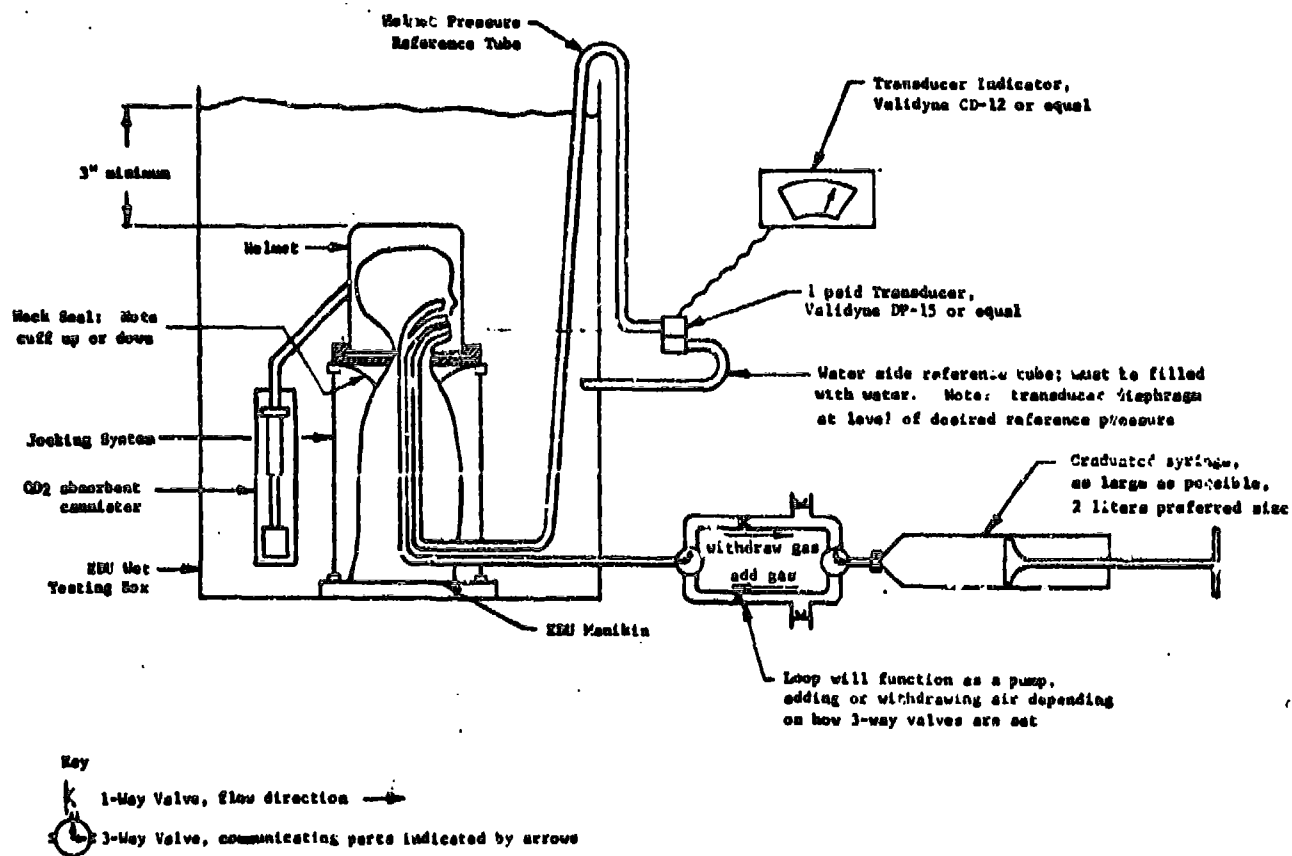


Figure 11
Test Equipment Set-up, Mixed Gas, Helmet Compliance Tests,
Helmet Wet. For Dry Tests, Helmet & Manikin need not be
inside the Wet Testing Box

2. Venturi Efficiency and Exhaust Valve Performance Tests

a. Background

The purpose of these tests is to determine the performance characteristics of the gas supply system, the venturi and the exhaust valve when operating in the semi-closed circuit mode. The maximum open circuit mixed gas flow rates available for emergency maneuvers are also to be determined.

b. Quantities to be measured

- 1) Helmet gas consumption rate
- 2) Recirculation rate
- 3) Helmet pressure re the selected reference pressure
- 4) Helmet gas temperature
- 5) Over bottom pressure at the inlet to the helmet non-return valve
- 6) Pressure drop across the recirculation rate flowmeter (Figure 12, manometer #1)
- 7) Pressure drop across all components added for the purpose of measuring the backpack flow rate (Figure 12, manometer #2)
- 8) Pressure rise across the venturi (Figure 12, manometer #3)

c. Quantities to be Controlled

- 1) Umbilical size and length
- 2) Supply over bottom pressure
- 3) Depth
- 4) Air Control Valve Position
- 5) Exhaust Valve Position
- 6) Venturi Control Valve Position
- 7) Gas media

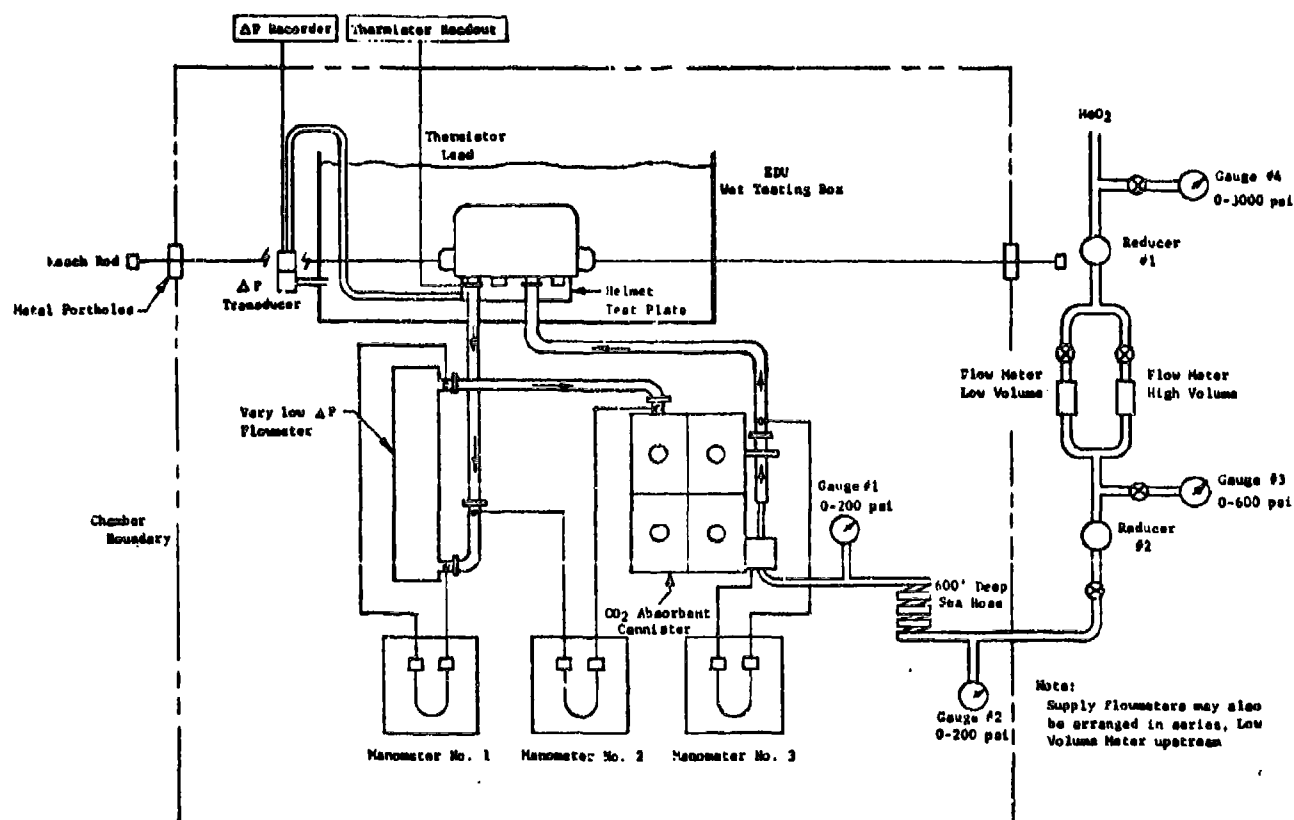


Figure 12
Test Equipment Set-up, Mixed Gas Helmet Venturi Efficiency and Exhaust Valve Tests.

d. Equipment

1) Specialized equipment required

- aa. Blank plate for the bottom of the helmet with provision for a pressure tap and thermistor.
- bb. Porthole blanks with reach rods or flexible shafts tailored to the helmet to be tested, 2 required.
- cc. Flowmeters (2) for gas supply line, approximate sizes, 1 and 8 scfm air at 70°F and 14.7 psia with a 600 psig minimum working pressure.
- dd. Very low pressure drop flow meter for the backpack suction hose. Capacity approximately 10 scfm air at 70°F and 14.7 psia with a rated pressure drop at the above conditions of less than 2 inches water.
- ee. Differential pressure transducer, ± 5 psid, and associated equipment.
- ff. Thermistor and read-out unit.
- gg. Wet testing box.
- hh. Water manometers (3), approximate Δp range, ± 20 inches H_2O .

2) Set up the test equipment generally as shown in Figure 12. Figure 12 is intended only as a guide, and minor equipment modifications can be expected to accommodate the particular apparatus under test. Only the helmet need be in the wet testing box (the exhaust valve needs to be submerged). The CO_2 absorbant unit, if desired, can be outside of the wet testing box as shown.

3) Determine how much umbilical is appropriate to the depths to be tested and install it as shown in Figure 12.

4) The Δp transducer should be set up to monitor the pressure differential between the helmet interior and the hydrostatic pressure at the exhaust valve centerline (chamber ambient pressure when helmet is tested dry), or at the level of the manikin's 7th cervical vertebra. See EDU report 19-73 for more information on the selection of the referenced pressure.

- 5) No remote actuation of the "chin button", if the helmet has one, is normally considered necessary. However, if desired, this can be accomplished with a third mechanical linkage such as a reach rod or a small pneumatic actuator.
- 6) Install markings around the reach rod handles so that helmet air control and exhaust valve positions can be quickly and accurately reproduced.
- 7) Use a fresh charge of baralyme in the canister.
- 8) Test all equipment for free operation. Test for leaks. Repair and/or adjust as required. Leaks in the gas supply system downstream from the flowmeters or in the helmet-to-test plate seal can invalidate the test. Leaks in the helmet and backpack will invalidate the helmet pressure data which is needed to define exhaust valve performance.

e. Calibration

- 1) Calibrate all instruments immediately prior to each major test. Re-check calibrations at the conclusion of the test.
- 2) The transducer should be calibrated against a water or mercury manometer; the thermistor against 32°F water and room temperature.
- 3) The flowmeter and gauges normally do not need daily calibration.

f. Test conditions

The test conditions to be covered will vary with the apparatus to be tested and with the degree of testing required. The Project Engineer should determine the conditions to be tested prior to commencing the test. Typical conditions for a complete test of the venturi efficiency and open circuit HeO₂ performance follow.

- 1) Umbilical 600' of standard deep sea diving hose ($\frac{1}{2}$ " I.D.)
- 2) Supply Pressure 50 psiob on oxygen*
100 psiob on HeO₂
other pressures as directed by Project Engineer
- 3) Test Depths and Supply Gas Mixtures

0,50 fsw	100% oxygen*
0,100,200,300 fsw	16% HeO ₂
300,400,450 fsw	10% HeO ₂
450,500,600 700	5% HeO ₂
700,800,900,1000	3% HeO ₂

*air is an acceptable and much safer substitute for this test.
- 4) Valve Positions

air control valve	closed, fully open
venturi control valve	fully open
exhaust valve	closed, $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$ and fully open

g. General procedures

- 1) Test all of the conditions of interest with the helmet on the surface. Get a feel for how the air control and exhaust valves operate and the effects of given valve openings. Leak check and de-bug the test equipment as required.
- 2) The basic procedure should be at each depth to test the helmet in the recirculating mode, then briefly open the air control valve fully open to measure the maximum open circuit flow rate possible and resulting helmet pressure. The open circuit test is important for predictions of how the helmet will perform in emergency situations. The air control valve should be opened only as long as is required to read the supply flowmeter and the helmet Δp transducer at the exhaust valve settings of interest since this procedure uses up mixed gas at a rapid rate.
- 3) Once the tests at one depth are complete, proceed to the next deeper depth and repeat. Watch for trends as the depth increases.

- 4) Repeat 25 to 50% of the test readings taken on descent again on ascent. This checks for reproducibility of the data.
- 5) Repeat 2), 3), and 4) as many times as required to obtain good confidence in the data.

h. Data handling

- 1) Record at each test condition all measured and controlled quantities on a pre-made data sheet. Carefully annotate all strip chart recordings or other permanent data records so that the data can be identified.
- 2) Plot the recorded data as directed by the Project Engineer.
- 3) Figure 13 shows some sample graphs.
- 4) For each test run calibration records for each instrument calibrated must be made, clearly annotated, and attached to the data generated by each respective instrument during the runs to which the calibration record applies. This applies in particular to instruments that generate written records such as the strip chart recorders.
- 5) The Project Engineer or his representative should keep a daily log of all significant events.

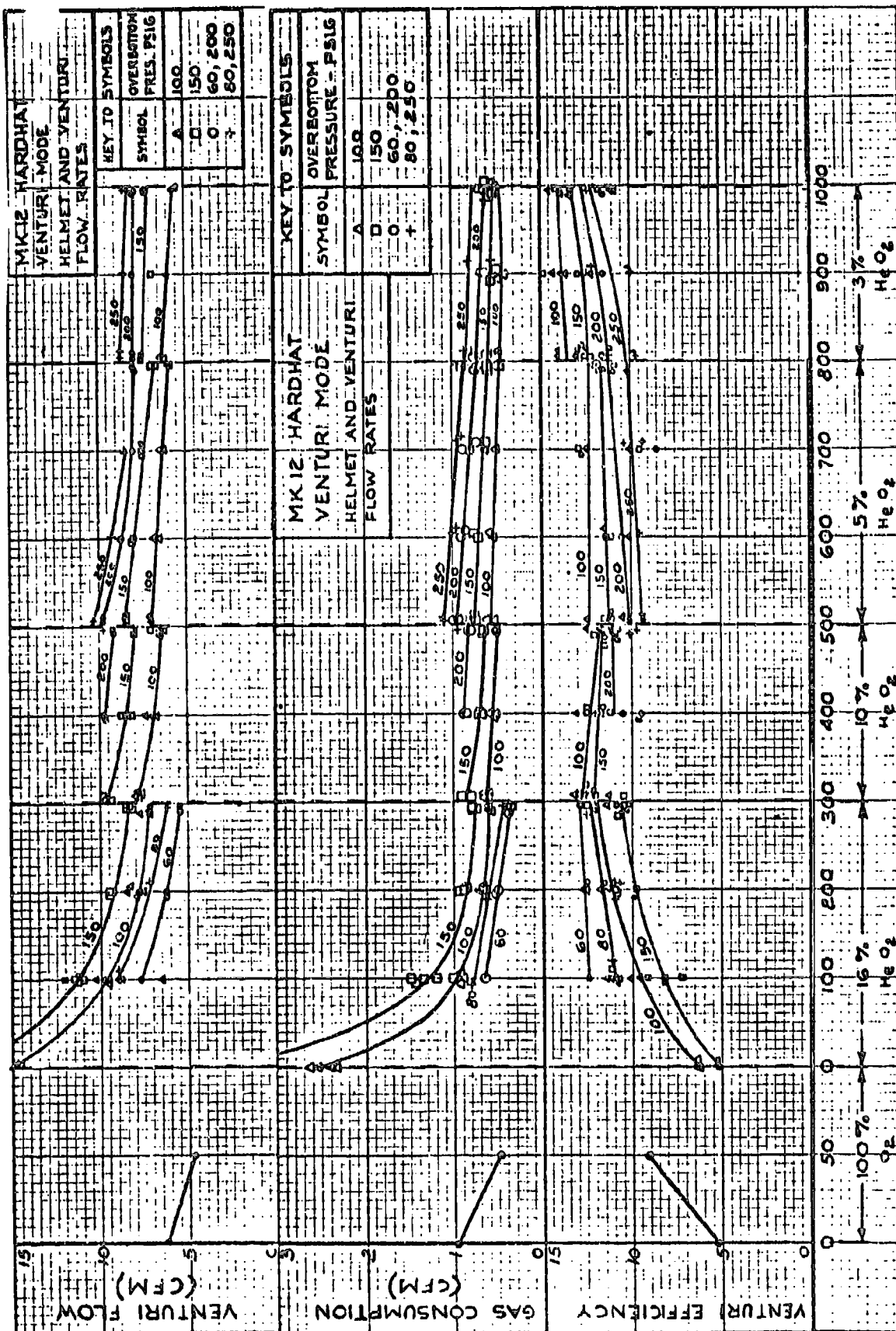


Figure 13
Sample Data Plots, Venturi Efficiency Tests

3. Sound Level Tests, Semi-Closed Circuit Mixed Gas Helmet

a. Background

The purpose of these tests is to measure the sound levels produced in the helmet under the conditions (depth, supply pressure, etc.) of normal HeO_2 diving operations, and to determine the hazard that they represent to the diver. The helmet gas consumption data accumulated during these tests can and should also be used as a check on the gas consumption rates measured under Section III. B. 2.

There is no sound level data available at this time in HeO_2 helmets tested submerged. However, it is reasonable to assume that the sound levels in a submerged HeO_2 helmet are comparable to those in the same helmet tested dry. This is usually the case with open circuit air helmets (See Section III. A. 3.a.). Since HeO_2 helmets produce fewer bubbles, and therefore have even less interaction with the water, it is quite acceptable to assume that submergence does not significantly affect their noise levels. Nonetheless, the helmet should be tested wet if possible.

Wet sound level testing is easier with HeO_2 helmets than with air helmets since the necessity of in-test valve manipulation can be avoided. However, since there is a lower rate of gas input into the helmet, there is also a greater danger of a helmet flood-out, especially if chamber descent is too rapid.

The recommended sequence is to test the helmet first dry, and then repeat limited portions of the dry tests with the helmet submerged. For the submerged tests as large a body of water as possible is preferred for the reasons cited in Section III. A. 3. a. Usually the water body of choice will be a wetpot, although the wet testing box can be used if necessary.

This test can be combined with Section III. B. 2. However, it is recommended that the two tests be performed separately. This allows for simpler tests, and it also produces some data redundancy which increases the confidence levels in the data.

b. Quantities to be Measured

- 1) Sound pressure levels at both diver ear positions, broadband and octave band levels.
- 2) Helmet pressure to the selected reference pressure, usually hydrostatic pressure at the exhaust valve centerline.
- 3) Helmet gas temperature
- 4) Overbottom pressure at the inlet to the venturi.
- 5) Pressure rise across the venturi

c. Quantities to be Controlled

- 1) Depth

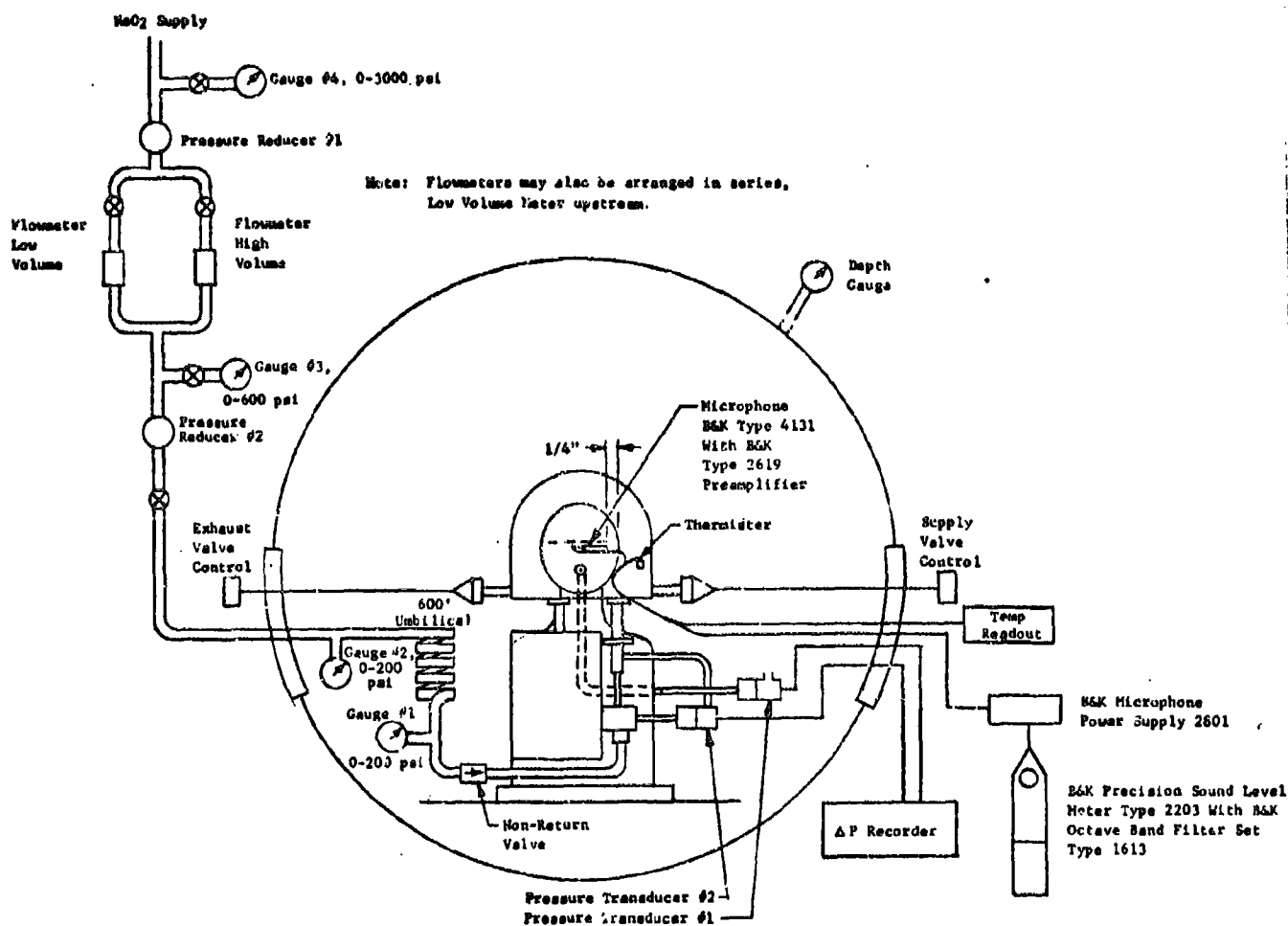


Figure 14
Test Equipment Set-up, Mixed Gas Helmet Sound
Level Tests, Helmet Shown Dry With a Neck Seal

- 2) Supply overbottom pressure
- 3) Air control valve position
- 4) Exhaust valve position
- 5) Position of helmet on test manikin
- 6) Manikin orientation
- 7) Helmet condition: wet or dry
- 8) Extraneous noise sources
- 9) Gas media
- 10) Umbilical size and length

d. Equipment

- 1) Specialized equipment required
 - aa. Accoustical testing manikin; EDU manikin, CBS Accoustical Manikin, or equal.
 - bb. Porthole blanks with reach rods or flexible shafts tailored to the helmet to be tested. One each for the air control and exhaust valves. It is possible to do without these, but it is much more convenient to have them installed.
 - cc. Flowmeters (2), approximate sizes, 1 and 8 scfm air at 70°F and 14.7 psia with a 600 psig minimum working pressure.

dd. Differential pressure transducer, approximate range ± 5 psid, and associated signal conditions and recorders.

ee. Thermistor and read-out unit

ff. Sound level equipment as per Figure 14 or equal.

- 2) Set up the test equipment as shown in Figure 14. If both ear positions are to be tested at the same time, the sound level equipment shown will need to be duplicated.
- 3) Determine how much umbilical is appropriate to the depths to be tested and install it as shown in Figure 14.
- 4) Install markings around the reach rod handles so that helmet air control and exhaust valve positions can be quickly and accurately reproduced.
- 5) If a neckseal helmet is to be tested as shown in Figure 14, augment the seal between the neckseal and the manikin's neck with tape (Band-AirTM Skin Tape, Duct Tape, Ordnance Tape all will work). If the helmet is to be tested with a full suit (as for example a USN MK 5 HeO₂ helmet), select a suit with cuffs, place the manikin inside the suit and bring the necessary wires, etc. out through one of the sleeves. Securely restrain the bottom of the suit so that it does not inflate. One of the best ways to do this is to simply roll it up and tie it off. Close the sleeves with flat clamps taking care not to damage the microphone and thermistor wires.
- 6) Use a fresh charge of CO₂ absorbent in the canister.

- 7) Test all equipment for free and normal operation. Test for leaks. Repair and/or adjust as required. Leaks in the gas supply system downstream from the flowmeters or in the neckseal-to-manikin seal can invalidate the flow rate data. Leaks in the helmet, neckseal (or suit) and through the manikin will tend to falsely increase the measured sound levels.

e. Calibration

- 1) Calibrate all adjustable instruments immediately prior to each major test. Re-check calibrations at the conclusion of the test.
- 2) The transducer should be calibrated against a water or mercury manometer; the thermistor against 32°F water and room temperature.
- 3) The flowmeter and gauges normally do not need daily calibration.
- 4) The microphone and sound level meter should be calibrated with a B&K Type 4230 Sound Level Calibrator or equal.

f. Test Conditions

The test conditions to be covered will vary with the apparatus to be tested and with the degree of testing required. The Project Engineer should determine the conditions to be tested prior to commencing the test. Typical conditions for a complete test of the sound levels occurring in the helmet under normal semi-closed operation follow:

1. Helmet Dry

Umbilical

600' of standard
deep seal diving hose
(1/2" I.D.)

Supply Pressure

50 psiob on oxygen or air*
100 psiob on HeO₂ ,
other pressures 2 ,
as directed by the
Project Engineer

Test Depths and Supply Gas Mixtures

0, 50 fsw	Air*
0, 100, 200, 300 fsw	16% HeO ₂
300, 400, 450 fsw	10% HeO ₂
450, 500, 600, 700 fsw	5% HeO ₂
700, 800, 900, 1000 fsw	3% HeO ₂

* Air has accoustical properties similar
to oxygen and is much safer to use.

Valve Positions

Air control valve

Closed

Venturi control valve

Fully open

Exhaust valve

Closed, 1/2 open
fully open*

* If exhaust valve position does not affect
sound levels, use only the fully closed
position.

2. Helmet Wet

Use as many of the above dry mode test
conditions as Project Engineer deems
necessary. Exhaust valve settings of
other than fully closed are not recommended
due to the increased possibility of a helmet
flood-out at lower helmet pressures.

3. Open Circuit Sound Levels

At selected test conditions at each depth the air control valve should be opened fully. Maintain this condition just long enough to record the helmet sound levels, helmet Δp and helmet gas consumption rate. This allows a determination of the helmet sound levels during vents and during emergency mixed gas open circuit operation should it ever be required. These open circuit tests may be run during either or both of dry and wet tests outlined above.

g. General Procedures

- 1) Measure the chamber background noise. Background noise from all sources, room noise, electrical noise, etc. should read less than 70 dB in all octave bands. Slightly higher levels can, however, be tolerated in the 31.5, 63 and 125 Hz center frequency octave bands.
- 2) Test all of the conditions of interest with the helmet dry and on the surface. Get a feel for how the air control and exhaust valves operate and the effects of given valve openings. Leak check and de-bug the test equipment as required.
- 3) Test the helmet under pressure, dry as shown in Figure 14. Test under the test conditions designated by the Project Engineer. The best sequence to follow is usually to do all of the test conditions at 0 fsw, then 50 fsw, etc. on down to the maximum test depth.
- 4) During ascent from the maximum test depth repeat 25 to 50% of the test readings taken during descent. This checks for reproducibility of the data.
- 5) Watch the helmet Δp transducer reading during descent. Be careful not to descend so

rapidly that helmet pressure becomes less than chamber pressure. During the wet tests this could produce an immediate flood-out.

- 6) Once the dry tests in 1) through 4) above are completed, run the wet tests. This will require either the wet testing box or the wetpot.
- 7) Repeat 3), 4) and 6) above as many times as required to obtain good confidence in the data obtained.

h) Data Handling

- 1) Record at each test condition all measured and controlled quantities on a pre-made strip chart recordings or other permanent data records so that the data can be identified.
- 2) Correct the octave band sound pressure level readings from the sound level meter for the microphone sensitivity loss under increased pressure. See the microphone manual or Reference 3 for the octave band correction factors.
- 3) From the corrected octave band sound pressure levels, determine the equivalent A-weighted sound pressure level from Figure 7. Determine the maximum daily exposure from Figure 8. Consult References 4 and 5 for further information.
- 4) NOTE: The dBA scale on the sound level meter cannot normally be used except at 0 fsw due to the uneven effect increasing ambient pressure has on the frequency response characteristics of the microphone. See Reference A and KAVXDIVINGU Reports 10-73 and 12-73 for more information on this effect.

- 5) Table 1 represents a typical data sheet.
- 6) For each test run calibration records for each instrument calibrated must be made, clearly annotated, and attached to the data generated by each respective instrument during the runs to which the calibration record applies. This applies in particular to instruments that generate written records such as the strip chart recorders.
- 7) The Project Engineer or his representative should keep a daily log of all significant events.

4. Ventilation Tests, Semi-Closed Circuit Mixed Gas

a. Background

The purpose of these tests is to determine the ventilation characteristics of the helmet when used in the semi-closed circuit mixed gas mode. The variables of primary interest are helmet Δp , helmet gas consumption, canister flow rate and PCO_2 levels in the helmet and in the manikin's inspired gas.

The performance of the venturi and helmet exhaust valve during these tests can and should be used as a check on the results obtained in Sections III. B. 2 and III. B. 3. Also when the helmet is tested with a neckseal, the pressure variations induced in the helmet by the manikin's respiration should be predictable from the helmet compliance results of Section III. B. 1 and the exhaust valve performance results of Sections III. B. 2 and III. B. 3.

Measuring the duration of the CO_2 absorbant canister is not a goal of these tests. Canister duration tests should be run separately as in Section III. B. 5. The tests outlined in this section are designed solely to determine the ventilation characteristics of the helmet given a properly operating CO_2 absorbant canister.

b. Quantities to be Measured

1) PCO_2 levels at the following locations

- aa. Inhalation mixing box (inhaled PCO_2 level, CO_2 #1, Figure 15)

- bb. Exhalation mixing box (exhaled PCO_2 level, CO_2 #2, Figure 15)
 - cc. Inlet to helmet exhaust valve (CO_2 #3, Figure 15)
 - dd. Canister suction hose (or pipe) (CO_2 #4, Figure 15)
 - ee. Canister return hose (or pipe) (CO_2 #5, Figure 15)
 - ff. Any other location(s) selected by the Project Engineer
- 2) Helmet pressure relative to hydrostatic pressure at the selected level.
 - 3) Helmet gas temperature.
 - 4) Canister flow rate and pressure drop across flowmeter.
 - 5) Venturi pressure rise.
 - 6) Overbottom pressure at the inlet to the helmet non-return valve (Gauge #1, Figure 15).
 - 7) Relative humidity of inspired air.
- c. Quantities to be controlled
- 1) Depth
 - 2) Supply overbottom pressure (Gauge #2, Figure 15)
 - 3) Air control valve position
 - 4) Exhaust valve position
 - 5) Position of helmet on test manikin
 - 6) Manikin orientation
 - 7) Helmet condition: wet
 - 8) Water bath temperature
 - 9) Gas media
 - 10) Umbilical size and length
 - 11) Manikin respiratory parameters

Note: Flowmeters may also be arranged in series, Low Volume Meter upstream.

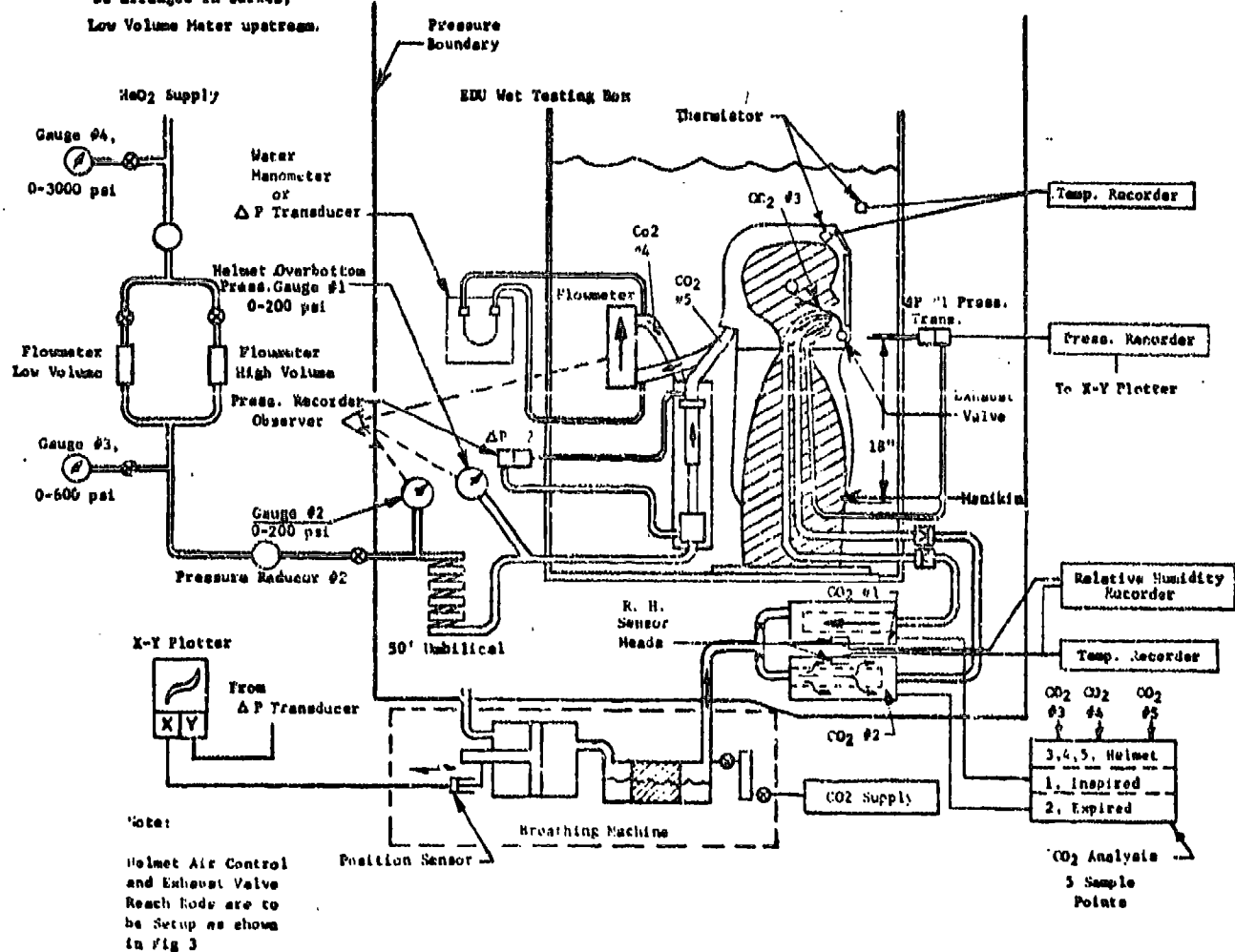


Figure 15.
Test Equipment Setup, Ventilation test Semi-closed Circuit Mixed Gas Helmet

- aa. CO₂ addition rate
- bb. Breathing rate
- cc. Tidal volume
- dd. Volume-time waveform
- ee. Exhaled gas temperature and relative humidity

d. Equipment set-up

1) Specialized equipment required

- aa. EDU manikin with double treacheas, one for inhalation, one for exhalation. Manikin should also have provisions for monitoring the pressure and temperature inside the helmet and for obtaining up to 4 gas samples from selected locations within the helmet and neckseal or suit.
- bb. Porthole blanks with reach rods or flexible shafts tailored to the helmet to be tested. One each for the air control and exhaust valves.
- cc. Flowmeters (2) for gas supply line, approximate sizes, 1 and 8 scfm air at 70°F and 14.7 psia with a 600 psig minimum working pressure.
- dd. Very low pressure drop flow meter for the backpack (canister) suction hose (or pipe). Capacity approximately 10 scfm air at 70°F and 14.7 psia with a rated pressure drop at the aforementioned conditions of less than 2 inches H₂O.
- ee. Differential pressure transducers (2), approximate range ±5 psid, and associated signal conditions and recorders.
- ff. Thermistor and read-out unit.
- gg. Breathing machine with inhalation and exhalation mixing chambers.
- hh. At least 2 CO₂ analysers, one with a range of 0 to 0.5% by volume or 0 to 1.0% by volume, one with a range of 0 to 6% by volume. CO₂ level #2,

(Figure 15, exhalation mixing box) can be expected to run between 4 to 6% S.E. CO₂ level #5, canister return hose can be expected to run 0 to 2.0% S.E.

- 2) Set up the equipment generally as shown in Figure 15. Figure 15 is intended only as a guide, and minor equipment modifications can be expected to accommodate the particular apparatus under test. The equipment set-up for these tests is essentially that used for the open circuit air tests plus a canister flowmeter, venturi Δp transducer, and an additional CO₂ sampling point.
- 3) Determine how much umbilical is appropriate to the depths to be tested and install it as shown in Figure 15.
- 4) One Δp transducer should be set up to monitor the pressure differential between the helmet interior and the hydrostatic pressure at the exhaust valve centerline (chamber ambient pressure if helmet is tested dry), or at the level of the manikin's 7th cervical vertebra. Use a different reference pressure if so directed by EDU report 19-73. The other should be set up to monitor the pressure rise across the venturi. Water manometers can be used if additional Δp indications are desired as in Section III. B. 2.
- 5) Install markings around the reach rod handles so that helmet air control and exhaust valve positions can be quickly and accurately reproduced.
- 6) The internal free volume of all inhalation plumbing components must not be greater than 10 liters. The internal free volume of all exhalation plumbing components must likewise be less than 10 liters. The internal free volume of components used for both inhalation and exhalation is to be charged against both 10 liter limits. 10 liters free volume is the most free volume that can be tolerated without introducing excessive errors due to pneumatic compliance (gas compressibility). See EDU Report 20-73, Section III for more details.
- 7) Total mechanical compliance (hose stretch, etc.) of the breathing loop plumbing must

be kept below .05 liter per 20 cm H₂O pressure change.

- 8) Water depth over the top of the helmet should be at least 6 inches. Water temperature should be 70 to 80°F.
- 9) If the helmet is to be tested with a dry suit, cut a suit at approximately the waist level and fasten to the manikin with a band clamp and tape at a level 18" below the exhaust valve centerline as shown in Figure 15. The simulation will not be complete with this equipment set-up because a diver when he inhales normally makes up the air volume he inhaled from the helmet-suit combination by chest expansion. Thus in reality the total suit volume remains essentially uninfluenced by the diver's respiration whereas with the set-up shown in Figure 15 it will be influenced slightly. The errors introduced by this deviation from actual conditions are normally negligible. If a better simulation is desired, a counter-lung may be placed around the manikin's chest and plumbed to the reference side of the breathing machine piston. This, however, must be done with great care so as not to inadvertently cause a loss of free communication between chamber ambient pressure and the pressure on the reference side of the breathing machine piston. This procedure is, therefore, not recommended unless absolutely essential to the validity of the test to be run.
- 10) If the helmet is to be tested with a neckseal, be certain that the neckseal fits very snugly to the manikin's neck. If helmet flooding or neckseal leakage is still a problem, augment the neckseal-to-manikin neck seal with tape (Band-AidTM Skin Tape, Duct Tape, Ordnance Tape work well), but be careful not to restrict the movement of the neckseal any more than necessary.
- 11) Set up the X-Y plotter so that it makes plots of helmet pressure versus inspired-expired volume. Plots of helmet pressure versus inspiratory-expiratory flow rates may also be useful.
- 12) The CO₂ sampling system should be sized so

that the time required for a gas sample to travel from the helmet to its appropriate analyser is less than 30 seconds at the maximum test depth.

- 13) All CO₂ sampling lines should have small water traps.
- 14) All breathing loop components should have an I.D. of not less than 3/4". The lengths of the hoses between the SCUBA mouthpiece and the manikin are not critical and may be as long as required so long as the 10 liter free volume limit of 6) above is observed. The lengths of the hoses and pipes between the SCUBA mouthbit and the breathing machine are important and should be kept as short as possible with reasonable effort.
- 15) The output of the Δp transducers must be continuously recorded. Continuous recording of the outputs of the CO₂ analysers is highly recommended. The output of the Δp transducer varies so rapidly with time that it cannot be read from a panel meter. The outputs of the CO₂ analysers will vary enough with time to make accurate readings from a panel meter extremely difficult.
- 16) Test all equipment for free operation. Test for leaks. Repair and/or adjust as required. Leaks in the gas supply system can invalidate the flow rate data. Leaks in the breathing loop plumbing can invalidate the CO₂ data. The breathing loop plumbing can be considered leak tight if, with the manikin's mouth sealed or corked shut, the system will hold both a 20 cm H₂O pressure and a 20 cm H₂O vacuum with a pressure (vacuum) decay rate of less than 1 cm H₂O per 10 seconds at 20 cm H₂O pressure (vacuum).

e. Calibration

- 1) Calibrate all adjustable instruments immediately prior to each major test. Re-check calibrations at the conclusion of the test.
- 2) The transducers should be calibrated against a water or mercury manometer; the thermistors against 32°F water and room temperature.

- 3) The flowmeter and gauges normally do not need daily calibration.
- 4) The CO₂ analysers should be calibrated against at least 3 known gases each: full scale, zero and mid-range CO₂ concentrations. If the CO₂ analyser calibrations are non-linear several more calibration points and a graphical calibration record will be required.
- 5) Calibrate the X-Y plotter axes prior to each test. Re-check at the conclusion of each test. Y axis should read helmet pressure; the X axis, inspired-expired volume.

f. Test conditions

The test conditions to be covered will vary with the apparatus to be tested and with the degree of testing required. The Project Engineer should determine the conditions to be tested prior to commencing the test. Typical conditions for a complete test of semi-closed mixed gas helmet follow:

- 1) Umbilical 50' standard $\frac{1}{2}$ " I.D. deep sea hose. No open circuit tests are to be done so umbilical length is not a factor.
- 2) Supply Pressures 50 psiob on oxygen*
100 psiob on HeO₂
Other pressures as directed by Project Engineer
- 3) Test Depths and Supply Gas Mixtures

0,50 fsw	100% oxygen*
0,100,200,300	16% HeO ₂
300,400,450	10% HeO ₂
450,500,600,700	5% HeO ₂
700,800,900,1000	3% HeO ₂

*Air is an acceptable substitute.

- 4) Valve Positions

air control valve	fully closed
venturi control valve	fully open
exhaust valve	fully closed, $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$ and fully open

- 5) Position of Helmet on Manikin

Normally jocked position. Be sure this position is known in sufficient detail that it can be <u>exactly</u> reproduced.

- 6) Manikin Orientation

Head-up Vertical, other orientations may also warrant testing, especially the face-down horizontal position.
--

- 7) Helmet Condition

Wet

- 8) Water Bath Temperature

70° to 80°F

- 9) Manikin Respiratory Parameters*

CO ₂ Addition Rate	.04 X RMV slpm (ex. 1.6 slpm at 40 lpm RMV)
Breathing Rate	15, 20 and 25 breaths per minute
Tidal Volume	1.5, 2.0 and 2.5 liters per breath respectively at breathing rates of 15, 20 and 25 bpm
Volume-Time Waveform	Flattened Sinusoid with an exhalation to inhalation time ratio of 1.1 to 1.0 and a ratio of peak flow to minute volume of 2.7
Exhaled Gas Temperature	97 ± 2°F
Exhaled Relative Humidity	Saturated at 97°F

*Parameters recommended by EDU Report 19-73

g. General procedures

- 1) These tests are normally done only with the helmet wet.

- 2) Test all of the conditions of interest with the helmet on the surface. Get a feel for how the exhaust valve operates and the effects of given valve openings. Leak check and debug the test equipment as required.
- 3) Test the helmet under pressure. Test under the test conditions designated by the Project Engineer. The best sequence to follow is usually to do all of the test conditions at 0 fsw, then 50 fsw, etc. on down to maximum test depth.
- 4) During descent be very careful not to travel too fast and produce a negative pressure in the helmet relative to chamber pressure. This would quickly result in a flooded helmet.
- 5) It is usually best to let the breathing machine run continuously unless 4) above requires that it be secured during descent.
- 6) During all times when the respiratory load on the helmet is being increased (increasing minute volume or increasing depth) watch the helmet Δp transducer output very carefully. If excessively negative Δp 's are observed, stop or slow down.
- 7) During ascent from the maximum test depth repeat 25 to 50% of the test readings taken during descent. This checks for reproducibility of the data.
- 8) Maintain each test condition until all values stabilize. This may take as long as 15 minutes.
- 9) If canister break-through occurs (CO_2 level #5, canister return, exceeds 0.5% S.E.), return to the surface obeying 7) above, replace the CO_2 absorbant, return to the depth of break-through and complete the tests desired.
- 10) Repeat 3) and 7) above as many times as required to obtain good confidence in the data.
- 11) Take care that the amount of gas being drawn out the gas sample lines does not disturb conditions in the helmet. It is usually wise to make the helmet Δp measurement and X-Y plots with all the sample lines secured.

h. Data handling

- 1) On-line cross checking of data values is essential for this test. The best cross check to use is simple CO₂ conservation. There are 2 checks that can be used.
 - aa. PCO₂ #2 - PCO₂ #1 should equal 4.0%
S.E. ± .3% S.E.
 - bb. The CO₂ addition rate should equal the CO₂ disappearance rate.
$$\text{CO}_2 \text{ in} = \text{CO}_2 \text{ out} = (\text{PCO}_2 \text{ \#4} - \text{PCO}_2 \text{ \#5}) \times (\text{canister flow rate}) + (\text{PCO}_2 \text{ \#3}) \times (\text{helmet gas consumption rate})$$

The first term on the right hand side of the equation is the rate of CO₂ removal by the CO₂ absorbant canister; the second is the rate at which CO₂ is exhausted out the helmet exhaust valve. The CO₂ disappearance rate calculated as above should equal the CO₂ add rate ± 10%.

See Appendix A in EDU Reports 10-73 and 12-73 for more details.
- 2) Record at each test condition all measured and controlled quantities on a pre-made data sheet. Carefully annotate all strip chart recordings or other permanent data records so that the data can be identified.
- 3) For each test run calibration records for each instrument calibrated must be made, clearly annotated, and attached to the data generated by each respective instrument during the runs to which the calibration record applies. This applies in particular to instruments that generate written records such as the strip chart recorders and X-Y plotter.
- 4) Plot the recorded data as directed by the Project Engineer. EDU Report 12-73, Figures 13, 14 and 15 show possible ways of presenting some of the data. Tables 4 and 5 of that report likewise show possible ways of organizing it in tabular form.
- 5) From the plots of helmet pressure versus inspired-expired volume made on the X-Y plotter, calculate the external work of breathing expended by the manikin. Compare against the .17 Kg-m/liter ventilation limit proposed by

EDU Report 19-73. If the work of breathing standards proposed by EDU Report 19-73 are adopted, a plot of the external work of breathing will also be required.

- 6) The Project Engineer or his representative should keep a daily log of all significant events.

5. CO₂ Absorbent Canister Duration Tests

a. Background

The purpose of these tests is to determine the expected lifetime of the CO₂ absorbent canister under all of the conditions in which the helmet will be expected to operate.

These tests are very similar to those of Section III. B. 4. The experimental set-up is identical. The principal differences are in the test conditions selected. In these tests the ventilation conditions in the helmet are held constant (manikin RMV, exhaust valve position, etc.) and the temperature of the water bath is varied. In Section III. B. 4 the reverse was true.

Canister lifetime tests are extremely time consuming. Round-the-clock operation should be considered.

b. Quantities to be measured

The quantities to be measured are the same as those in Section III. B. 4. b. Inspired gas temperature and relative humidity are however of critical importance whereas in Section III. B. 4 they were of secondary interest.

c. Quantities to be Controlled

The quantities to be controlled are the same as those in Section III. B. 4. c. Water bath temperatures,

manikin exhaled gas temperature and relative humidity are, however, of critical importance here whereas in Section III, B. 4. they were of secondary interest.

d. Equipment Set-up

- 1) The recommended equipment set-up is identical to that outlined in Section III, B. 4. d.
- 2) Precise ($\pm 2^\circ\text{F}$) control of the water bath temperature is essential.

e. Calibration

The calibration procedures are the same as those outlined in Section III, B. 4. e.

f. Test Conditions

The test conditions to be covered will vary with the apparatus to be tested and with the degree of testing required. The Project Engineer should determine the conditions to be tested prior to commencing the test. Typical test conditions for a complete canister lifetime test follow:

- | | |
|---------------------|--|
| 1. Umbilical | 50' standard 1/2" I.D. deep sea hose or equivalent. |
| 2. Supply pressures | 50 psio on oxygen
100 psio on HeO_2 ,
other pressures as directed by Project Engineer |

3. Test Depths and Supply Gas Mixtures

0,50 fsw	100% oxygen*
0,100,200,300	16% HeO ₂
300,400,450	10% HeO ₂
450,500,600,700	5% HeO ₂
700,800,900,1000	3% HeO ₂

* Air is an acceptable substitute

4. Valve Positions

Air control valve Fully Closed

Venturi control valve Fully open

Exhaust valve Fully closed

5. Position of helmet on manikin Normally jocked position. Be sure this position is known in sufficient detail that it can be exactly reproduced.

6. Manikin Orientation Head-up Vertical

7. Helmet Condition Wet

8. Water Bath Temperatures 70°F, 50°F, 32°F

9. Manikin Respiratory Parameters*

CO₂ Addition Rate 2.5 slpm

Breathing Rate 25 breaths per minute

Tidal Volume 2.5 liters

*Severe Work Rate Parameters Recommended by EDU Report 19-73.

Volume-Time Waveform

Flattened Sinusoid
with an exhalation to
inhalation time ratio
of 1.1 to 1.0 and a
ratio of peak flow to
minute volume of 2.7

Exhaled Gas Temperature $97 \pm 2^{\circ}\text{F}$

Exhaled Relative Humidity Saturated at 97°F

g. General Procedures

- 1) The only test conditions which are not constant throughout are depth and water bath temperature. The best procedure is usually to test all of the desired water bath temperatures at 0 fsw, then go to 100 fsw, etc. on down to the maximum depth to be tested.
- 2) Each individual test will consist of running the canister until breakthrough at one depth and one water bath temperature. The test is considered to start when the breathing machine is turned on. Once turned on, the breathing machine and CO_2 add system should not be secured until the test is completed.
- 3) Run the test until the CO_2 level in the canister return line reaches 1.0% S.E.
- 4) During these tests, once started, breathing machine must run continuously. During descent evolutions, use the air control valve to admit extra gas if required to maintain a positive helmet Δp during descent. Watch the helmet Δp indication very carefully during descent.
- 5) Due to the length of time required for each test, individual test runs are normally not repeated as long as everything worked

properly and the test results are consistent with other test runs.

- 6) Take care that the amount of gas being drawn out the gas sampling lines does not excessively disturb conditions in the helmet.

h. Data Handling

- 1) The data handling procedures are essentially the same as those of Section III. B. 4. h.
- 2) The CO₂ cross checking procedures are identical with those of Section III. B. 4. h. 1. As before, they should be done on-line.
- 3) The principal purpose of these tests is to determine the expected canister lifetime as a function of depth and water temperature. Consequently only the CO₂ level versus time data need be plotted separately. Whether or not other data obtained (helmet gas consumption, canister flow rate, helmet Δp , venturi Δp , etc.) is to be plotted is to be determined by the Project Engineer. The best way to handle this data will probably be to plot it as additional data points on the graphs and plots made as a result of the tests outlined in Sections III. B. 2. and III. B. 4.

6. Manned Dives, Subjective Evaluation, Semi-Closed
Circuit Mixed Gas Helmet

a. Background

Definitive manned testing of the helmet for ventilation adequacy will be accomplished under Section III.

B. 7, Physiological Testing.

This section is concerned with essentially subjective tests to obtain a rough measure of the comfort, human engineering and mobility of the helmet. To determine those qualities accurately requires a rather large program of manned tests considered to be outside the scope of this evaluation. The tests outlined below can be accomplished quickly and relatively easily. They will provide an indication of the helmet mobility, human engineering and comfort which should be sufficient to point out any really serious troubles that must be addressed before larger scale manned tests such as Techeval/Opeval are undertaken.

The instrumentation recommended below is relatively sparse. This is so not because of design, but rather due to the extreme difficulty of making measurements underwater on a diver who is free to move about as he chooses in a relatively large body of water; 8000 gallons in the case of an EDU Wetpot.

These tests are similar to the tests conducted under Section III. A. 5. on open circuit air helmets. The only major difference is the addition of gas analysers to monitor the performance of the CO₂ absorbent canisters.

b. Quantities to be Measured

- 1) Helmet gas consumption rate
- 2) Helmet PCO_2 level at:
 - aa. Inlet to exhaust valve
 - bb. Canister suction hose (or pipe)
 - cc. Canister return hose (or pipe)
- 3) Helmet oxygen level measured in the canister suction hose (or pipe)
- 4) Helmet Δp relative to hydrostatic pressure at the exhaust valve centerline. If a different reference pressure was used in Section III. B. 4, then use that reference pressure instead.
- 5) Helmet temperature
- 6) Helmet exhaust valve positions selected by the divers.

c. Quantities to be Controlled

- 1) Depth
- 2) Diver work tasks
- 3) Wetpot temperature
- 4) Supply overbottom pressure
- 5) Gas Media

d. Equipment

- 1) Specialized equipment required
 - aa. Flowmeters, approximate sizes, 1 and 8 scfm air at 70°F and 14.7 psia with a 600 psig minimum working pressure.
 - bb. Differential pressure transducers, approximate range ± 5 psid, and associated signal conditions and recorders.
 - cc. Thermistors and read-out unit
 - dd. CO₂ analysers, 0 to 1.0% by volume range with recorders.
 - ee. Oxygen analysers, 0 to 25% by volume range, with recorders
- 2) Set up the test equipment generally as shown in Figure 16. Figure 16 is intended only as a guide, and minor equipment modifications can be expected to accommodate the particular apparatus under test.
- 3) Regular umbilicals are not necessary for these tests. Any suitable leader hoses will do.
- 4) All gas sampling lines should have water traps.
- 5) The outputs of the O₂ and CO₂ analysers should be continuously recorded. The output of the Δp transducer must be continuously recorded. Hand recordings of the Δp , O₂ and CO₂ values every 5 minutes, as is commonly done, are of little value due to often rapidly changing values. The helmet flow rates are usually sufficiently steady to permit hand recording of the flowmeter readings.

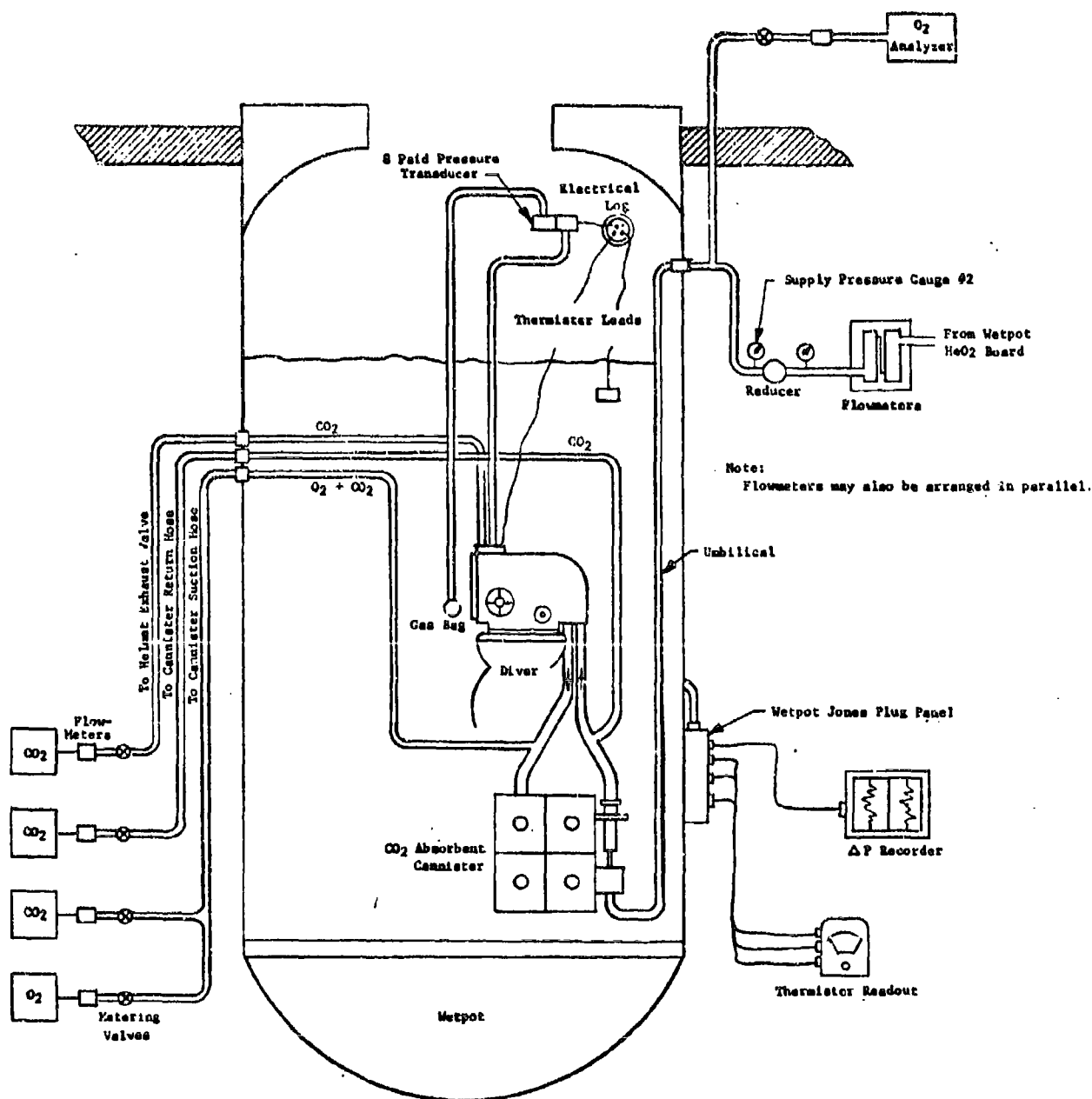


Figure 16
Test Equipment Set-up, Manned Subjective Tests,
Semi-Closed Circuit Mixed Gas Helmet

e. Calibration

- 1) Calibrate all adjustable instruments immediately prior to each major test. Re-check calibrations at the conclusion of the test.
- 2) The Δp transducers should be calibrated against a water or mercury manometer; the thermistors against 32°F water and room temperature.
- 3) The flowmeter and gauges normally do not need daily calibration.
- 4) All gas analysis instruments should be calibrated against at least 3 known gases each: full scale, zero and mid-range concentrations. If the analysers, especially the CO₂ analysers, are non-linear, several more calibration points and a graphical calibration record is required.

f. Test Conditions

The test conditions to be covered will vary with the apparatus to be tested and with the degree of testing required. The Project Engineer should determine the conditions to be tested prior to commencing the test. Typical conditions for a reasonably complete test of a surface supplied semi-closed circuit mixed gas helmet follows:

Depth	0,100,200,250,300,400 fsw
Supply Pressure (Measured on Gauge #2, Fig. 10)	50 psiob, when O ₂ used 100 psiob, when HeO ₂ used

Wetpot Temperature	70°F or above (due to wetpot steel NDT considerations)
Supply Gas	16% HeO ₂ at 0,100, 200,250,300 fsw 10% HeO ₂ at 400 fsw
Diver Work Tasks	See procedures subsection

Deeper dives would be required to evaluate some semi-closed systems which are designed to operate at very deep depths out of PTC's etc. Such dives are considered out of the scope of this section. They normally require saturation operations, and they can be accomplished neither easily nor quickly. Experience, however, has shown that the performance of venturi-powered recirculating systems varies only slightly with depths below 300 fsw (see EDU Reports 10-73, 12-73 and Reference 2). Consequently the test conditions outlined above are considered sufficient to obtain a good indication of the comfort, mobility and human engineering qualities of venturi-powered recirculating systems, regardless of their maximum operating depth.

g. General Procedures

- 1) For a reasonably thorough subjective evaluation at least 5 dives should be made to each depth. Always use divers who have had sufficient exposure on the helmet so that they feel familiar with its controls.
- 2) Normal U.S. Navy diving procedures are to be followed. While on the bottom the divers should alternate between 10 minute periods

of "moderate" work and 5 minute rest periods. Normally the work tasks alternate between lifting a 70-pound weight (78 lbs dry) a distance of 2-1/2 feet 10 times per minute and swimming against a trapeze designed to exert a steady backward force of 6.0 lbs. For an average diver, exerting a stationary swimming force of 6.0 lbs. produces an oxygen demand of approximately 1.26 standard liters per minute (6). This is equivalent to a respiratory minute volume of approximately 30 liters per minute (7) or to swimming in SCUBA at a steady speed of approximately 0.8 knots (6)(7). An oxygen demand of 1.26 slpm results in a CO₂ production of about 1.13 slpm (8). Working against an underwater bicycle or pedal ergometer is also a suitable task.

- 3) At the conclusion of each dive, the diver should fill out the applicable portions of the Diver Equipment Subjective Analysis Questionnaire reproduced in Appendix A.
- 4) Have several divers dis-assemble and re-assemble the helmet and CO₂ absorber assembly. Note any difficulties encountered.

h. Data Handling

- 1) Record at each test condition all measured and controlled quantities on a pre-made data sheet. Carefully annotate all strip chart recordings or other permanent data records so that the data can be identified.
- 2) Compare the CO₂ levels and helmet pressures and gas consumption rates measured to the results of Section III. B. 4. Compare the measured helmet PCO₂ and PO₂ levels with those predicted on the basis of the measured helmet flow rates and the diver CO₂ production and oxygen consumption rates expected as a result of the work tasks selected.

- 3) Tabulate and/or plot the data obtained as directed by the Project Engineer. There is usually sufficient variability in the data from these dives to make concise plotting difficult.
- 4) The Project Engineer or his representative should keep a daily log of all significant events.
- 5) For each day's test dives, calibration records must be made, clearly annotated and attached to the data generated by each respective instrument during the runs to which the calibration record applies.

7. Manned Dives, Physiological Testing

a. Background

The purpose of these tests is to determine quantitatively the ability of the apparatus under test to support the physiologic and respiratory requirements of a diver at hard work. The tests are normally conducted by the EDU Medical Department.

The procedures and equipment used for these tests is still being refined. A detailed protocol covering these tests is expected to be published by the EDU Medical Department sometime in the second quarter of CY 1974.

8. Emergency Air Mode Tests

a. Background

When diving in a semi-closed circuit mixed gas helmet, it can become necessary to switch to open circuit air if something happens to the CO₂ absorbent canister or the mixed gas supply. The tests outlined in this section are those tests appropriate to a mixed gas helmet being operated on emergency open circuit air.

A mixed gas helmet being operated on emergency open circuit air is for all intents and purposes an open circuit air helmet, and it can be tested as such. The only difference between testing a straight open circuit air helmet and testing a mixed gas helmet operating on emergency open circuit air is that the latter helmet has a CO₂ absorbent canister in place, but not operating (if the venturi does not have a shut-off valve, the CO₂ absorbent canister will be operating but on air). Since the CO₂ absorbent canister is not operating, it need not be instrumented.

b. Recommended Tests

- 1) The mixed gas helmet compliance test results of Section III. B. 1 are directly applicable and no special helmet compliance test is necessary.
- 2) The air supply system and exhaust valve tests of Section III. A. 2. should be performed. Some mixed gas helmets use the same exhaust valve as does a matching

air helmet. However, the air supply system is almost always different. With a mixed gas helmet the air usually must go through some additional plumbing before reaching the helmet air control valve.

- 3) The open circuit air sound levels of Section III. A. 3. should be performed. This test may be omitted if the mixed gas helmet under test has a matching open circuit air helmet for which the sound levels are known.
- 4) The ventilation tests of Section III. A. 3. must be performed. The ventilation characteristics of a mixed gas helmet used on emergency open circuit air are almost always different from the ventilation characteristics of the matching open circuit air helmet, if indeed there is one.
- 5) The manned subjective dives of Section III. A. 5. need be performed on only a limited scale.
- 6) Physiologic test dives as in Section III. A. 6. need not be performed.
- 7) The Project Engineer must decide which of the above tests are to be done on the particular helmet being evaluated, and which test conditions are to be used.

IV. INSTRUMENT SPECIFICATIONS

<u>Instrument</u>	<u>Type Normally Used</u>	<u>Accuracy</u>	<u>Minimum Frequency Response</u>
Flowmeters	Variable Area	±2% of full scale	0.5 Hz
ΔP Transducers	Variable Reluctance	±½% of full scale	200 Hz
Transducer Indicators	Meters	±1% of full scale	1 Hz
Oxygen Analysers	Paramagnetic	±0.5% by volume	0.1 Hz
CO ₂ Analysers	Non-dispersive Infrared	±1% of full scale	1 Hz
Thermistors	Thermocouple	±1° F	0.1 Hz
Relative Humidity Instruments	--	±3%	0.1 Hz
Pressure Gauges	Bourdon Tube	±½% of full scale	0.5 Hz
Strip Chart Recorders	Electric, Oscillographic	±1% of full scale, 50 mm chart width	40 Hz at full chart width
X-Y Plotter	--	±1% of full scale	maximum slewing speed = 40 in/sec

maximum
acceleration:
1400 in/sec²
in X direction.
2000 in/sec²
in Y direction.

REFERENCES

1. Material Test Procedure 10-2-192, Diving Equipment (Helmets, Belts, Divers Dress, Etc.), U.S. Army Test and Evaluation Command, Commodity Engineering Test Procedure, 23 March 1970
2. TECHEVAL Report, USN MK 12 Diving Outfit, in preparation
3. Thomas, W. G., Preslar, M. J. and Farmer, J.C., "Calibration of Condenser Microphones under Increased Atmospheric Pressures", Journal of the Acoustical Society of America, Vol. 51 Number 1 (Part 1), 1972 pp 6-14
4. Navy Department: Hearing Conservation Program. Bureau of Medicine and Surgery Instruction 6260.6B, 5 March 1970
5. "Criteria for a Recommended Standard, Occupational Exposure to Noise", U.S. Department of Health, Education and Welfare, 1972
6. Lanphier, E. H., Dwyer, J. V. and Walkowski, A. J., "A Trapeze Ergometer", Navy Experimental Diving Unit Formal Report 1-55, 18 March 1955
7. U.S. Navy Diving Gas Manual, Research Report Number 3-69, U.S. Navy Supervisor of Diving, Naval Ship Systems Command, October 1, 1969
8. Henkener, J. A., "Low-Pressure Compressed Air Breathing Systems Study. Part II. Mark V Helmet Ventilation Studies". Battelle Memorial Institute, September 22, 1970, p 16

APPENDIX A
DIVER EQUIPMENT
SUBJECTIVE ANALYSIS

DIVER EQUIPMENT
SUBJECTIVE ANALYSIS

DIVERS NAME _____ DATE _____

LOCATION _____ DEPTH _____ TIME _____

EQUIPMENT SET-UP

MANUFACTURER _____ MODEL _____

TYPE RIG _____ GAS USED _____ %O₂ _____ %N₂ _____ % He _____

SUPPLY-PRESSURE BEFORE _____ AFTER _____

REGULATOR PRESSURE BEFORE _____ AFTER _____

ORIFICE SIZE _____ LITER FLOW BEFORE _____ AFTER _____

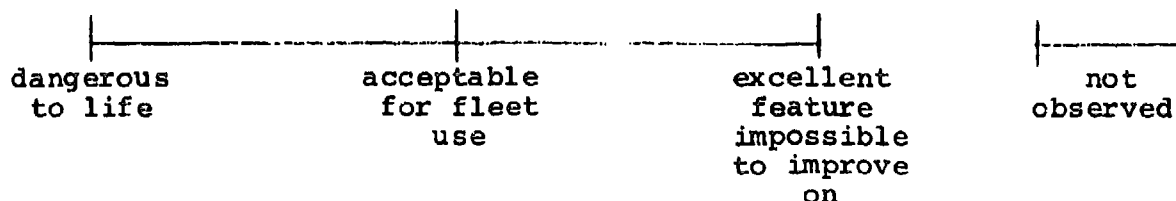
HELMETS AND MASK

1. WHAT INLET AND EXHAUST SETTINGS DID YOU FIND COMFORTABLE WHILE WORKING AND WHILE STANDING AT REST? EXPRESSE VALVE SETTINGS AS THE NUMBER OF TURNS OPEN OR CLOSED.
(example: inlet 2 1/4 turns open).

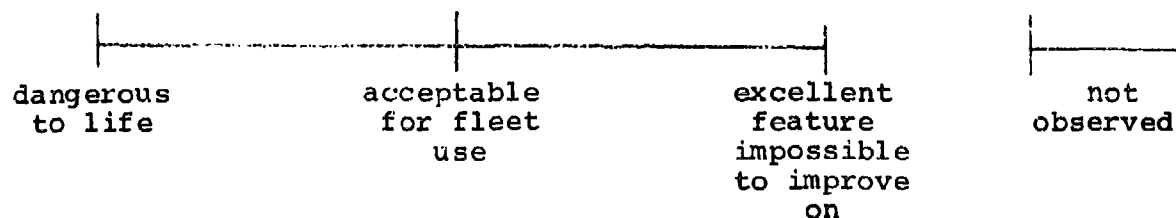
	INLET	EXHAUST
WORK	_____	_____
REST	_____	_____

TYPE OF WORK _____

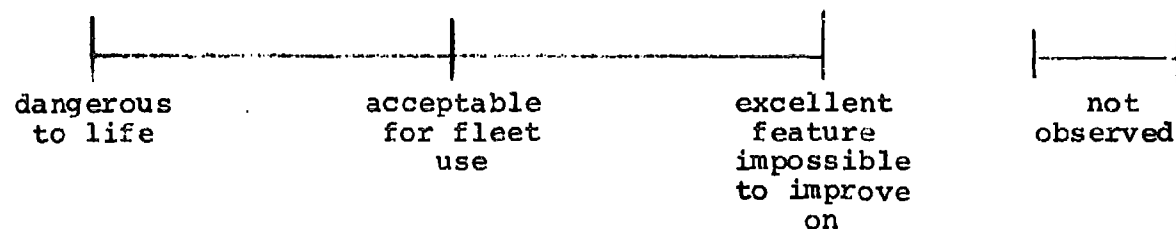
2. RATE AND COMMENT ON THE INHALATION RESISTANCE OF THE HELMET/MASK.



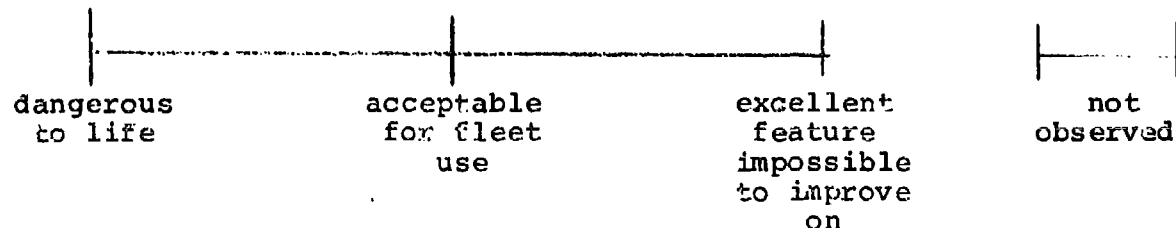
3. RATE AND COMMENT ON THE EXHALATION RESISTANCE OF THE HELMET/MASK.



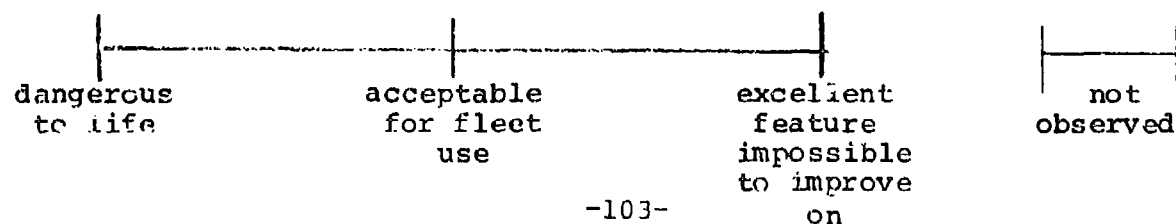
4. RATE AND COMMENT ON THE EASE OF DONNING THE HELMET/MASK AND ITS ACCESSORIES.



5. RATE AND COMMENT ON THE HELMET/MASK WEIGHT OUT OF THE WATER.



6. RATE AND COMMENT ON THE HELMET/MASK BUOYANCY IN THE WATER.



7. RATE AND COMMENT ON THE FIT AND COMFORT OF THE HELMET/MASK.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

8. RATE AND COMMENT ON THE NOISE LEVEL IN THE HELMET.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

9. RATE AND COMMENT ON THE ADEQUACY OF THE COMMUNICATIONS IN THE HELMET/MASK.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

10. RATE AND COMMENT ON THE ACCESSIBILITY AND OPERATION OF CONTROL VALVES.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

11. RATE AND COMMENT ON THE VISIBILITY FROM THE HELMET/MASK.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

12. RATE AND COMMENT ON THE EASE OF CLEARING WATER FROM THE HELMET/MASK.

<hr/>			
dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

13. RATE AND COMMENT ON THE HELMET/MASK TORQUE.

<hr/>			
dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

14. WHAT IS YOUR OVER ALL EVALUATION OF THE HELMET/MASK.

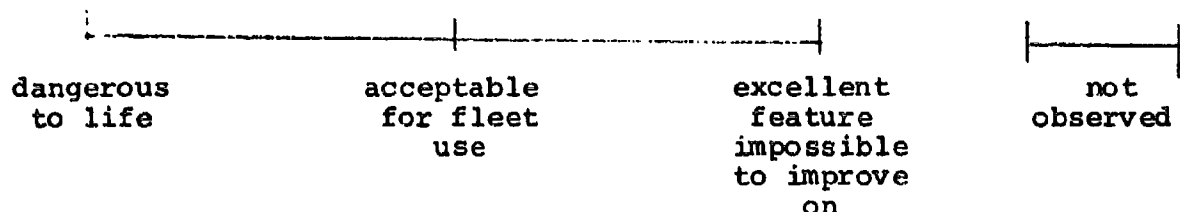
<hr/>			
dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

BREATHING APPARATUS

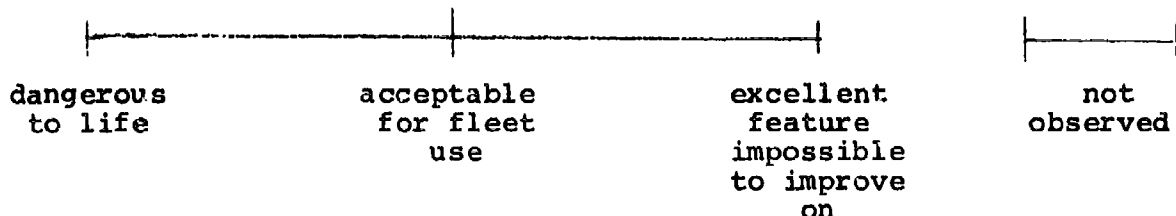
15. RATE AND COMMENT ON THE WEIGHT OF THE APPARATUS OUT OF THE WATER.

<hr/>			
dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

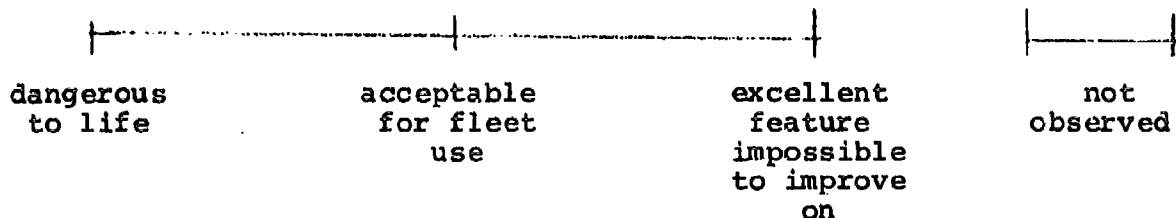
16. RATE AND COMMENT ON THE BUOYANCY OF THE APPARATUS IN THE WATER.



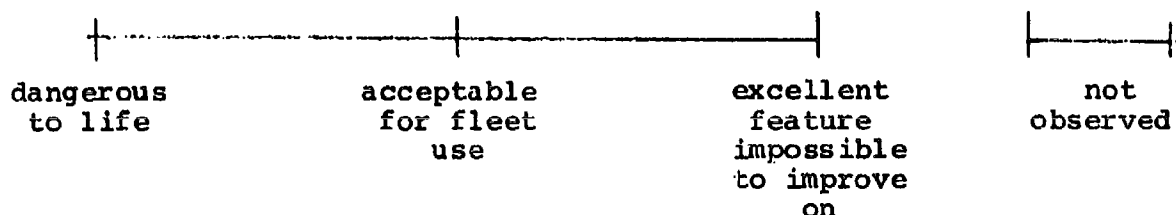
17. RATE AND COMMENT ON THE ACCESSIBILITY AND OPERATION OF CONTROL VALVES.



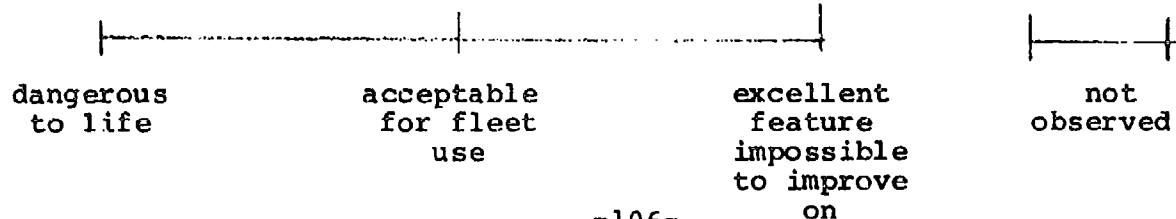
18. RATE AND COMMENT ON THE SWIMMABILITY OF THE APPARATUS.



19. RATE AND COMMENT ON THE APPARATUS TORQUE.



20. RATE AND COMMENT ON THE INHALATION BREATHING RESISTANCE.



21. RATE AND COMMENT ON THE EXHALATION BREATHING RESISTANCE.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed
----------------------	--------------------------------	--	-----------------

22. WHAT IS YOUR OVERALL EVALUATION OF THE APPARATUS.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed
----------------------	--------------------------------	--	-----------------